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JOURNAL OF ANATOMY AND PHYSIOLOGY

# ENDOCRANIAL CASTS AND BRAIN FORM: A CRITICISM OF SOME RECENT SPECULATIONS.

By J. SYMINGTON, M.D., F.R.S., *Professor of Anatomy, Queen's University, Belfast.*

EARLY in this year I published a Lecture[1] in which were described the results of an investigation made with the object of ascertaining the extent to which the inner surface of the cranial wall is moulded upon the opposed surface of the brain. In the course of this research a large number of endocranial, endodural, arachnoid, and brain casts were prepared from recent man. Duplicates of these casts have been presented to the Museums of the Royal Colleges of Surgeons of England and Edinburgh, where they are available for examination by those interested in this question.

For many years past palæontologists have made endocranial casts of the skulls of extinct animals in order to demonstrate the size and general form of the cranial cavity and also to gain an idea of the degree of cerebral development. Such casts are frequently called "brain casts," apparently on the assumption that the form of the brain is practically identical with that of the cranial cavity.

The degree of approximation of the cranial aspect of the brain to the interior of the skull differs considerably amongst the various members of the vertebrata, so that to call a cast of the cranial cavity a "brain cast" may be very incorrect, since such a cast may differ considerably both in size and form from the brain itself. The distinction between the terms "endocranial" and "brain" casts must now be specially emphasised, as several anatomists and palæontologists have within recent years used endocranial casts of dried and sometimes fragmentary skulls of man on which to base a description of the convolutionary pattern of his cerebral cortex and of other features of his brain. It is obvious that if these deductions rest upon a sound basis of observed facts this method opens up

[1] The Sir John Struthers Lecture "On the Relation of the Inner Surface of the Cranium to the Cranial Aspect of the Brain," *Edinburgh Medical Journal*, February 1915.

a very interesting line of research, by offering the prospect of important additions to our knowledge of the evolution of the brain of prehistoric man, and by yielding interesting particulars regarding the character of this organ in recent but deceased men whose brains have perished, but whose skulls are available for scientific study.

In this paper I propose to consider the evidence presented by Professors Eug. Dubois,[1] A. Froriep,[2] M. Boule and R. Anthony,[3] R. Anthony,[4] and Elliot Smith[5] in support of statements they have made regarding the brain in cases where they had the opportunity of studying endocranial casts of skulls in which the cranial wall was more or less perfectly preserved, but its contents destroyed. In my Struthers Lecture will be found a detailed account of the effect of the structures intervening between the skull and the brain in producing differences or permitting harmony between the shape of the inner surface of the skull and the outer surface of the brain. A careful comparison of a number of endocranial casts and of the corresponding brains is an essential preliminary task before attempting a reconstruction of the brain of ancient man from endocranial casts of his skull. In the course of this review I shall have occasion to consider how far the results of such work have been utilised.

## Endocranial Cast of *Pithecanthropus erectus*.

At the Fourth International Congress of Zoology, held in Cambridge in August 1898, Professor E. Dubois gave a communication on "The Brain Cast of *Pithecanthropus erectus*," which was published the following year in the *Proceedings* of the Congress. At the meeting he showed an endocranial cast of the celebrated skull-cap he found during excavations in Java in 1891–92. After directing attention to certain peculiarities in the general shape of the cast, he gave the following description of the markings of the cerebral fissures and convolutions which it presented:—

"In the frontal region of the hemispheres the convolutions are most

[1] "Remarks upon the Brain Cast of *Pithecanthropus erectus*," *Proc. of the Fourth International Congress of Zoology held in Cambridge in 1898.*

[2] "Ueber den Schaedel und andere Knochenreste des Botanikers Hugo v. Mohl," *Archiv für Anthropologie*, Bd. viii., 1909.

[3] "L'Encéphale de l'homme fossile de la Chapelle-aux-Saints," *L'Anthropologie*, tome xxii., 1911.

[4] "L'Encéphale de l'homme fossile de la Quina," *Bulletin et Memoires de la Société d'Anthropologie de Paris*, 1913. (Communicated to the Society 18th July 1912).

[5] "Preliminary Report on the Cranial Cast," an appendix to a paper by C. Dawson and A. Smith Woodward "On the Discovery of a Palæolithic Human Skull and Mandible in a Flint-bearing Gravel overlying the Wealden (Hastings Bed) at Piltdown Common, Fletching, Sussex," *The Quarterly Journal of the Geological Society*, vol. lxix. pt. 1, March 1913. (Communicated to the Society 18th December 1912.)

perfectly distinct. Those on the left side are a little different from those on the right side; the latter are, further, best preserved. For first orientation the central and precentral fissures are easily identified. The intraparietal fissure is only very partially distinct, but seeming to point to a relatively large occipital lobe, an ape-like condition, undoubtedly consequent on a relatively larger development of the sensory centres of the cortex in contrast with smaller areas of association. In the neighbourhood of the median part of this sulcus the brain is very flat.

"The most conspicuous feature is the second frontal fissure, as clearly developed as in any human hemisphere, originating in the common T-shaped form from a clearly distinct inferior precentral sulcus and having the shape of a reversed ∞. The two segments of this fissure encircle the two limbs of perfectly definite Y-shaped anterior branches of the fissura Sylvii, the stem of which is about 1 cm. long.

"The second frontal sulcus is only very partially preserved on the left side.

"On both sides a median frontal fissure is very marked.

"The first frontal fissure is interrupted in different places, a condition common in the apes as well as in man.

"The important inferior frontal convolution has attained a fair development. I found the area of its exposed superficies equal to half the average area in twelve European hemispheres, but at least double that in the brain of a large chimpanzee or an orang-utan. This seems to indicate that our fossil being possessed already a certain amount of power of speech. The pars triangularis is present in this convolution, as results from the presence of two anterior branches of the Sylvian fissure. But the pars opercularis has only a very rudimentary development" (p. 82).

Unfortunately, so far as I have been able to ascertain, no duplicates of this cast have been issued and no photographs or drawings published, although it is sixteen years since Dubois read his paper. Under these circumstances it is impossible for me to examine the evidence on which Dubois made such precise and definite statements regarding the convolutions of the anterior part of the brain of *Pithecanthropus*. I understand Dubois intends to publish a fuller report on his cast, but this long delay is greatly to be regretted, as the specimen is unique and of the greatest scientific value. An excellent ectocranial cast was made by Dubois soon after his return from Java. It has been widely distributed, and a copy of this cast was used by Professor Schwalbe in his elaborate "Studien ueber *Pithecanthropus erectus*" in the *Zeitschrift für Morphologie und Anthropologie*, Bd. 1, 1899.

## Endocranial Cast of Mohl's Skull.

In 1906 Professor A. Froriep had the opportunity of examining the skeleton of Hugo v. Mohl, a former Professor of Botany in the University of Tuebingen. Mohl died in 1872, and his remains were exhumed about thirty-four years later. The vaulted portion of the skull was found intact; it included the frontal bone down to the supraorbital prominences, and the occipital to slightly below the grooves for the transverse sinuses. The sphenoid and ethmoid were decayed, and also most of the lower part of the occipital. The two temporals were preserved, except that the squamous portions were somewhat damaged. The missing parts were reconstructed and an endocranial cast made. It is evident from these facts that the part of the cast exposed in the norma verticalis is natural, but that the normæ laterales are artificial over the anterior part of the temporal lobe, the orbital surface of the frontal lobe, and the main stem of the Sylvian fissure.

So far as the number and general distribution of the digital impressions are concerned, the cast does not show any peculiarity as compared with those I have made from dissecting-room subjects and described in my Struthers Lecture.

In Froriep's article in the *Archiv für Anthropologie* he gave on plate vii. five photographic reproductions of his endocranial cast, viz. vertical, frontal, occipital, and right and left lateral views, and on plate viii. similar photographs of a model of Mohl's cerebral hemispheres. The method by which this "Gehirnmodell" was prepared from the endocranial cast and the results obtained are of interest. The endocranial cast showed the ridges due to the meningeal vessels and the elevations indicating the depressions on the bone caused by the Pacchionian bodies. These were all removed, and the plaster was also cut away along the middle line to mark the position occupied by the superior sagittal sinus and on each side for the transverse sinus. Furrows were also cut in the course of what Froriep considered to be depressions indicating the position of a number of the principal cerebral fissures. In figs. 1 to 4 are reproduced Froriep's photographs of his cast viewed from the norma verticalis and left norma lateralis before this procedure and after its conversion into a brain model. I am unable to satisfy myself either from Froriep's photographs of his endocranial cast, or, more important still, from a duplicate of this cast which I have had the opportunity of studying, of the existence of depressions of sufficient distinctness to justify the mapping out of the fissures shown in figs. 2 and 4.

In the left norma lateralis the middle and inferior temporal convolutions are as usual well marked: the superior temporal sulcus is possibly somewhat

exaggerated in making the reconstruction; part of the posterior limb of the Sylvian fissure is distinctly indicated, but its upturned posterior end, as well as the ascending anterior branch of this fissure, are in my opinion marked on the brain model without any satisfactory indication of their existence on the endocranial cast.

Even if we accepted, which I certainly cannot, Froriep's brain model as accurately defining the course of the main fissures on Mohl's brain, it is instructive to ascertain what it teaches us with regard to the degree of

FIG. 1.—Norma verticalis of endocranial cast of von Mohl's skull (Froriep).

FIG. 2.—Norma verticalis of Gehirnmodell (Froriep).

development of his convolutions. Mohl was a distinguished botanist and one of a family of very talented brothers, and therefore we might reasonably anticipate that his cerebral cortex would exhibit at least an average degree of complexity. It is true that the results of the careful study of the brains of a number of distinguished men have not, on the whole, proved that their cerebral hemispheres possess a marked advance in the complexity of the convolutionary pattern over ordinary individuals, but in Mohl's case the various views of the model of his brain would serve admirably as a representation of the hemispheres of a seven or eight months' fœtus. The appearance of the central, precentral, superior and inferior frontal and intraparietal fissures in Mohl's "Gehirnmodell" suggest this early stage in

their development. It is evident that Froriep can only have intended to represent the course and position of the main fissures, the secondary ones not being sufficiently definite to warrant their addition. Even, however, with regard to the main fissures, his representation of their appearance must be regarded merely as a simple diagrammatic view and not an exact picture of the tortuous course they so often pursue. If from an endocranial cast only the general directions of the main fissures can be determined, and the secondary and even tertiary ones, which are essential for an estimate of the degree of cerebral development, have to be omitted, it is obvious that the evidence afforded by an endocranial cast is useless

Fig. 3.—Left norma lateralis of endocranial cast of von Mohl's skull (Froriep).

Fig. 4.—Left norma lateralis of Gehirnmodell (Froriep).

in forming a reasonable estimate of whether or not the individual from whose skull it was taken possessed a simple, an average, or a complex type of convolutions. Froriep considers that Mohl had a richly convoluted brain, and he bases this conclusion upon the fact that in the profile and occipital views of the endocranial cast the main convolutions are not simple, but are composed of a large number of small prominences.

As is readily seen on figs. 1 and 3, the prominences on this endocranial cast due to the digital impressions are practically limited to the lower part of the frontal, temporal, and occipital lobes. They are even less marked than in several casts I have made from dissecting-room subjects, and I have taken a cast of the occipital end of the skull of a native Australian in which the digital impressions above the transverse sinus are quite as numerous as in Mohl's skull.

## Endocranial Cast of La Chapelle Skull.

Science is indebted to Professor Boule for a series of very valuable and well-illustrated memoirs[1] on the La Chapelle skeleton and its associated remains. This fossil man belongs to the Neanderthal race; the skull is very large, and Boule estimates the cranial capacity as amounting to 1620 c.c., or distinctly above the average of modern civilised races. An endocranial cast of this skull was studied by Boule and Anthony[2] with the special object of endeavouring to form an estimate of the degree of cerebral development. For purposes of comparison they obtained similar casts of the anthropoid apes, of the Neanderthal skull-cap, and of various races of modern man. A number of these casts were those prepared by Broca in connexion with his classical researches on cranio-cerebral topography. Their paper is illustrated by photographs of the endocranial cast of the La Chapelle skull viewed from various aspects. Duplicates of this cast, with those of the outer aspect of the same skull, were made in the Museum d'Histoire Naturelle, and a limited number issued to subscribers. Through the kindness of Professor Thane I have had the opportunity of studying both the ectocranial and endocranial casts.

Boule and Anthony admit that the traces of the convolutions left on the inner surface of the cranial wall give only an approximate idea of their real appearance, and they compare such traces to the view of a statue from which one is not allowed to remove the veil. They also state that the appearance of the convolutions when *in situ* is liable to differ somewhat from that seen on a brain which has been removed from its cavity and preserved, and that such differences are liable to mislead an observer who is not cautious and has only one cast under examination. They accordingly attach special importance to the comparison of a number of endocranial casts with one another.

It is evident that they had no sets of endocranial, endodural, arachnoid, and brain casts prepared from bodies in which the brain had been properly hardened *in situ* by means of formol so as to avoid any appreciable shrinkage of the brain, nor indeed do they seem to have had suitably preserved brains to compare with endocranial casts from corresponding subjects. They write:

"Nous nous sommes surtout attaché à comparer l'objet de notre étude aux moulages endocraniens dont nous disposions" (p. 130). But surely it is much more important to compare a series of endocranial casts with the corresponding brain casts or hardened brains. The real question to be

[1] "L'homme fossile de la Chapelle-aux-Saints," *L'Anthropologie*, xx., 1909; and *Annales de Palæontologie*, 1911–13.

[2] *Op. cit.*, p. 112.

solved is, What do endocranial casts teach us regarding the brain? And the mere comparison of endocranial casts one with another can yield no direct evidence as to the degree of complexity of the convolutions of the corresponding brains, however useful they may be in forming an estimate of the general size and shape of the brain and in demonstrating variations in the markings on the inner aspect of the cranial wall.

In the "Introduction" to their paper they say:

"Notre travail nous a conduits à cette conclusion que l'encéphale de l'homme fossil de la Chapelle-aux-Saints présente un ensemble de caractères d'infériorité plus nombreux et plus marqués que l'encéphale de n'importe quel Homme actuel. S'il est humain à la fois par son volume absolu et par son volume relatif, il paraît se rapprocher de celui des Anthropoides par la plupart des détails de sa morphologie."

The large size of the endocranial cast would certainly alone justify the assumption that the brain was human, for it is nearly three times greater than that of the largest anthropoid apes. It is necessary, however, to examine some of the reasons advanced in support of their important conclusion that the brain of the La Chapelle man possessed more numerous and more important marks of inferiority than any modern race of men and that these characters indicated an approach towards the anthropoids. Boule and Anthony consider that the traces of the cerebral convolutions which are found on the endocranial cast of the La Chapelle skull are fewer, less complicated, and coarser than those on similar casts of modern man, and they assume that such endocranial markings prove that the brain of the La Chapelle man possessed a simple or low type of convolutions. I cannot assent to either of these propositions, as I have failed to discover any special peculiarities in the form and distribution of the digital impressions on the endocranial cast as compared with those in modern man. The number and depth of the digital impressions on recent skulls are well known to vary considerably, and those of the La Chapelle fall well within the normal range of variation. Further, my own observations upon a considerable number of sets of endocranial and brain casts have satisfied me that the degree of simplicity or complexity of the convolutions cannot be accurately estimated from endocranial casts.

Boule and Anthony discuss at some length the peculiarities in the position of the branches of the Sylvian fissure and of the insular opercula as compared with modern man and the apes. It would be useless to refer to their comparative results, because in my opinion the data upon which they are based are unsound. In attempting from their endocranial cast to determine the position of the anterior branches of the Sylvian fissure and the "cap" of Broca, or frontal operculum, they have made serious mistakes.

The main grounds on which such an adverse opinion is expressed will be evident from a comparison of figs. 5 and 6. Fig. 5, which is a diagram of the right lateral aspect of the La Chapelle brain, is reproduced from Boule and Anthony's paper. *Spa.* and *Spp.* indicate the position of the anterior and posterior pre-Sylvian fissures which form the anterior and posterior boundaries of the frontal operculum. In fig. 6 is seen a photograph of the right norma lateralis of the skull of a female sixty-one years old, on which has been outlined the fissures of the corresponding portion of the right hemisphere. The two anterior branches of her Sylvian fissure are

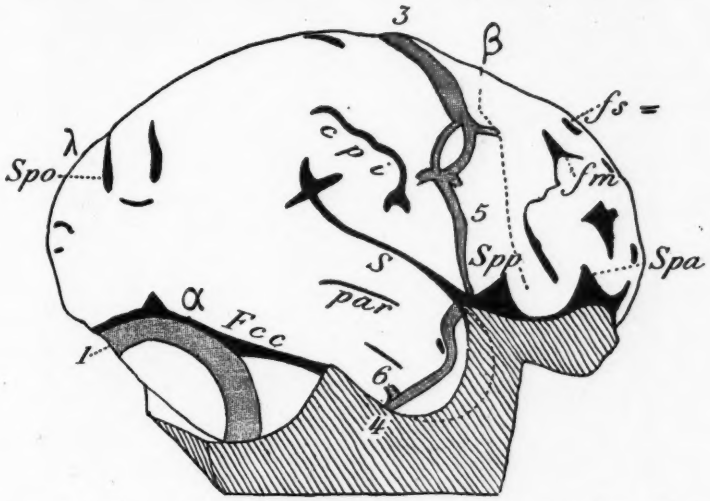



Fig. 5.—Diagram of right norma lateralis of endocranial cast of La Chapelle skull (Boule and Anthony).

seen to belong to the U-shaped type, and in this respect correspond to the arrangement represented in fig. 5. Here, however, the resemblance ceases. In the La Chapelle brain both branches appear to pass upwards from the rounded margin separating the orbital and lateral surfaces of the frontal lobe on to the lateral surface of the frontal lobe. Both fissures ascend, and the posterior one is at the level of a coronal plane passing through the anterior end of the temporal lobe. It is difficult to understand how the "cap" of Broca in such a position could form an operculum to the central lobe unless this lobe extended much further forward than is normal in the adult human brain, or the forward growth of the temporal lobe was defective. If such an arrangement of parts actually existed in the

La Chapelle brain, it would form an interesting comparison with a fœtal brain of about the seventh month (see fig. 275, *Quain's Anatomy*, 11th edition, vol. iii. pt. i.).

The brain represented in fig. 6 shows the "cap" of Broca and its associated Sylvian branches to be distinctly farther back, and this is undoubtedly the usual position.

The lateral boundary of the orbital surface of an endocranial cast is

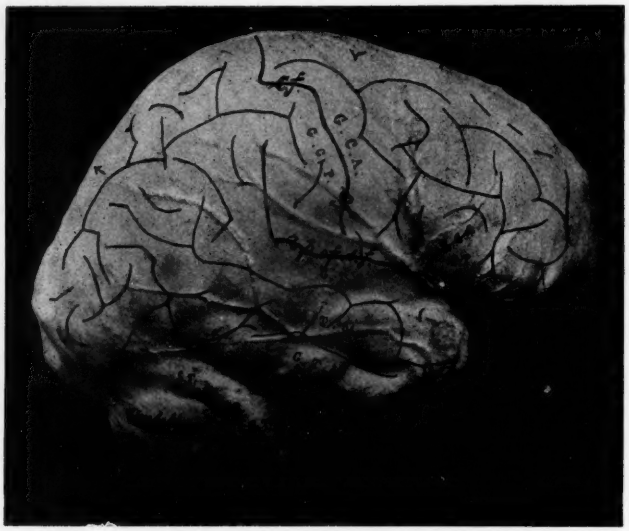


Fig. 6.—Photograph of the right norma lateralis of an endocranial cast of the skull of a female sixty-one years old. On this is outlined the fissures of the corresponding part of the brain. ½ nat. size.

*c.f.*, central fissure; *r.p. of s.f.*, posterior branch of Sylvian fissure; *r.a.a.*, anterior ascending branch of Sylvian fissure. Inferior ascending branch not labelled; it lies below P.T., P.T. (pars triangularis).

often marked by one or more grooves which may correspond to lateral offshoots of the sulcus orbitalis on the orbital surface of the frontal lobe of the brain. Boule and Anthony were evidently making a very doubtful guess in representing these grooves as markings due to the pre-Sylvian fissures. The rashness of their attempt to localise these fissures is enhanced by the fact that in the reconstruction of the skull Boule was unable, from the pieces of the skull found, to reconstruct the roof of the right orbit and the anterior boundary of the right middle fossa of the base of the skull, so that the endocranial cast does not show the actual

form of the orbital surface of the frontal lobe or the anterior end of the temporal lobe of the brain, these having been reconstructed.

Fig. 7 is a photograph of the endocranial cast of the La Chapelle skull viewed from above. Upon this I have marked all the fissures represented by Boule and Anthony in fig. 8 of their paper in *L'Anthropologie*, tome xxii.

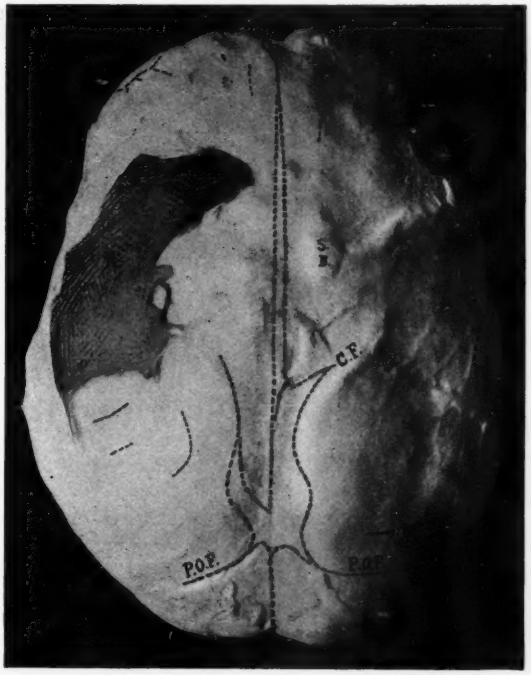



FIG. 7.—Photograph of the norma verticalis of the endocranial cast of La Chapelle skull on which is marked the position, according to Boule and Anthony, of certain cerebral fissures. ½ nat. size.

P.O.F., parieto-occipital fissure; C.F., upper part of central fissure; S.B., sinus of Breschet; R, area where cranial wall was defective.

The parieto-occipital are the only fissures whose entire course on this aspect of the brain are depicted, only traces of a few other fissures being shown, so that the convolutionary pattern on the vault is very incompletely illustrated. In the case of the fissures that are marked, Boule and Anthony appear to have assumed that any faint depression on the endocranial cast would correspond to some fissure.

If there is one point in cranio-cerebral topography that can readily be demonstrated, it is that on the vault near the median plane the superior cerebral veins, lacunæ laterales, superior sagittal sinus, Pacchionian bodies, and the cerebrospinal fluid, which tends to accumulate in this position, separate, in a number of places, the under surface of the skull from the adjacent cortex, so that the cerebral fissures and convolutions leave no markings on the endocranial cast of sufficient distinctness to enable one to determine their position and extent.

I have endocranial casts of the vault of ten skulls, each with a cast of the related part of the brain. My laboratory assistant, Miss Rea, has very carefully transferred the outlines of the cerebral fissures on to the endocranial casts. In no single instance do these fissures correspond to definite depressions indicating their position, and very frequently, in various parts of their course, they lie over eminences on the cast.

## Endocranial Cast of the Piltdown Skull.

Fortunately it does not fall within the scope of this paper to give a detailed account of the somewhat acrimonious discussion which accompanied various attempts to reconstruct the Piltdown skull and to estimate the form and capacity of its cranial cavity. It is, however, necessary to mention some facts connected with that controversy which have a direct bearing on the important question of the probable size and shape of the brain of this primitive man.

In Dr Smith Woodward's account of the first reconstruction of the skull, published in March 1913, he gave the cranial capacity of the Piltdown man as 1070 c.c. (see table of comparative measurements on p. 130 of his paper in the *Quarterly Journal of the Geological Society* for March 1913), but this estimate is modified in the text as follows:—

"The capacity of the brain case cannot, of course, be exactly determined; but measurements both by millet-seed and by water show that it must have been at least 1070 c.c., while the reconstruction of the missing parts suggests that it may have been a little more" (p. 126). On a duplicate of an endocranial cast of the reconstructed skull made under Dr Smith Woodward's direction by Mr F. O. Barlow in 1912, and sold by Mr R. F. Damon, I found the water displaced was nearly 100 c.c. more than the amount given in the comparative table already mentioned. Apparently as a result of a vigorous attack by Professor A. Keith in August 1913 on the accuracy of this reconstruction, Dr Smith Woodward reconsidered the question, and finally prepared a second one, the endocranial cast of which has a capacity of almost exactly 1300 c.c., or an increase of 230 c.c. as

compared with his table of measurements, and about 130 c.c. more than the first cast. As the Piltdown cranial fragments represented less than half of the entire cranial wall, and important parts on both sides of the median plane were not found, it is obvious that it was impossible to make more than an approximately accurate reconstruction, and anatomists will, I believe, recognise the care and skill bestowed by Dr Smith Woodward, Dr Pycraft, and Mr Barlow on this difficult piece of work. It is unfortunate that in the table of comparative measurements the Piltdown skull is represented as possessing a lower cranial capacity than the Gibraltar, Neanderthal, and a typical Australian skull, whereas on the basis of the second reconstruction it is greater than any of these. It is obvious that any estimate of the Piltdown brain must vary according to the particular endocranial cast selected for examination.

Professor Elliot Smith's "Preliminary Report on the Cranial Cast" was made in December 1912, and was based upon an examination of the endocranial cast of Dr Smith Woodward's first reconstruction. His opinion does not appear, however, to have been materially modified by subsequent criticisms of this cast, for in a communication to the Geological Society of London more than two years later (in April 1914), he wrote as follows:—

"On the present occasion it is not my intention to say anything further in reference to the brain of *Eoanthropus* (because I am preparing a full report upon it for presentation to the Royal Society); but, as there has been considerable criticism of the restoration of the brain case, I should like to take this opportunity of expressing my opinion that none of the criticism has affected the accuracy of the preliminary note upon the cranial cast which I communicated to this Society in December 1912 (p. 93).

"As the correct restoration of the cranium was the necessary preliminary to any detailed study of the form of the brain, Dr Smith Woodward kindly permitted me to examine the fragments of the skull, and make an independent investigation with the view of determining what positions they originally occupied in the skull. This examination revealed a multitude of structural features which indicate precisely the true position and orientation of each of the fragments; and there is no doubt that the reconstruction of the skull which Dr Smith Woodward exhibited to the Geological Society in December 1912 was a much closer approximation to the truth than any of the various models so far exhibited in public by his critics."

The full report thus referred to was communicated to the Royal Society on the 19th December 1914, but no account of it has up to the present been published either in its *Proceedings* or *Transactions*. As Elliot Smith still adheres to the views he expressed in 1912 on the Piltdown brain, and as there

appears to be but little prospect of the early appearance of his full report on this question, I must base any criticisms I have now to make on the very brief and condensed statement contained in his "Appendix." In this he wrote:—

"At first sight the brain presents a considerable resemblance to the well-known Palæolithic brain casts, and especially to those obtained from the Gibraltar and La Quina remains, which are supposed to be women's. Like these casts, this one is relatively long, narrow, and especially flat; but it is smaller, and presents more primitive features than any known human brain or cranial cast" (p. 146).

I have already emphasised the importance of distinguishing between "endocranial" and "brain" casts, and the paragraph just quoted shows the confusion that may result from such lax terminology. It may seem unnecessary to point out that no one has hitherto been fortunate enough to obtain casts of the brain of Palæolithic man, although a number of more or less perfect endocranial casts have been made.

The question of the capacity of the Piltdown cranial cavity has already been considered, and it must surely be admitted that the assertion that it is smaller than any known human brain or cranial cast was premature and cannot now be maintained.

The further claim advanced by Elliot Smith that the Piltdown endocranial cast presents "more primitive features than any known human brain or cranial cast" necessarily requires a more detailed examination. The primitive features mentioned by Elliot Smith to which I propose to refer are the simplicity of the cerebral sulci and of the associated convolutionary pattern, and certain peculiarities in the development of the temporal and parietal lobes of the brain.

With reference to the cerebral sulci and convolutions we now give two quotations from his preliminary report:—

"In this note I do not propose to discuss the significance of the faint glimmerings which this cast affords of the pattern of the convolutions, except to remark that there are indications sufficiently definite to enable us to blot out a great part of the singularly primitive arrangement of sulci" (p. 146), and "unfortunately there are only very slight indications of the arrangements of the furrows upon the surface of the cerebral hemispheres. Nevertheless many of them can be detected, if not by sight, by passing the finger over the surface and locating the depressions by touch. These features are represented (with considerable exaggeration so far as depth is concerned) in the diagram (fig. 11) on the preceding page" (p. 146).

It is evident from these extracts that Elliot Smith found that the depressions and elevations on the endocranial cast, which apparently

corresponded to the cerebral convolutions and fissures, were very indistinctly marked, and he assumed from the "faint glimmerings" of the convolutions on the cast that the Piltdown man possessed a brain with "a singularly primitive arrangement of sulci." I have reproduced his sketch (fig. 8), which, although diagrammatic, illustrates admirably those features which he regards as of special significance. It will be noticed that none of the furrows which he has represented on the cast are named or described. More cautious than Froriep, or Boule and Anthony, he does not attempt to define the course and extent of even the main fissures, and

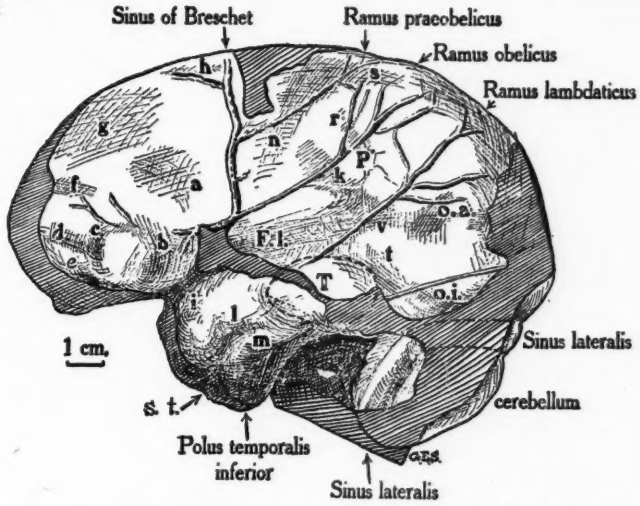



FIG. 8.—Left norma lateralis of the internal cast of the skull from Piltdown (Elliot Smith).

although letters are scattered with profusion over his diagram, not one cerebral fissure or convolution is named. The letters *s*, *n*, *k*, *v*, and *o.a.* are said to be placed on "recognisable sulci," but further details are not given, except that they circumscribe an elevated area of the parietal lobe.

I need not repeat the details of the researches recorded in my Struthers Lecture regarding the relations between endocranial and brain casts, and will content myself with saying that the evidence furnished by the markings on the cranial aspect of the Piltdown bone fragments do not justify the statement that the Piltdown man had a singularly primitive arrangement of the cerebri sulci, and this dictum can only, at the most, be regarded as a plausible hypothesis.

The next feature of the Piltdown brain to be considered is the temporal lobe. This is described by Elliot Smith as follows:—

"One of the most striking features of this brain cast is the deep excavation of the temporal area, to form the wide bay between the inferior temporal pole and the cerebellum. This is due to the marked attenuation of the temporal region; but as we have already seen in the case of the parietal region, so also here are definite signs that the expansion has begun which eventually will transform this area into the very different configuration that it presents in the modern brain. There is a very prominent elliptical swelling; the summit (at T) is raised more than a centimetre above the level of the surrounding cortex. It is 2 centimetres in vertical measurement, and almost 3 centimetres long. This peculiar configuration assumes quite a special interest when it is remembered that this obviously expanding area occupies the position where, in the modern human brain, is developed the territory which recent clinical research leads us to associate with the power of spontaneous elaboration of speech and the ability to recall names (Adolf Meyer).

"The configuration of the anterior part of the temporal area is also peculiar, though a suggestion of the same kind of form is seen in the Gibraltar brain cast. Below the point marked *l* the surface slopes inwards towards the mesial plane, so that the fulness of the temporal pole of the modern brain is wanting" (p. 147).

The deep excavation referred to above is a characteristic feature of all human endocranial casts. It is due mainly to the upward projection of the petrous portion of the temporal bone, but is completed behind by the groove for the descending portion of the transverse sinus and in front by the great wing of the sphenoid. Smith Woodward describes the left temporal bone of the Piltdown skull as "typically human in every detail," and with this statement I am in agreement. The only peculiarity of the bone, and this it shares with the other cranial fragments, is its great thickness. The thickness does not affect, except to a slight extent, the form of the cranial cavity. I have made several endocranial casts of this region on the skulls of modern man, in which the general shape and dimensions of this excavation are practically identical with those of Smith Woodward's endocranial cast of the Piltdown man. It must be remembered that no part of the sphenoid bone of the Piltdown skull was found, and therefore the exact configuration of the anterior part of the middle temporal fossa of the base of the skull cannot be ascertained.

The descent of the floor of the middle fossa of the base of the skull in the Piltdown man was supposed by Elliot Smith to be so marked that he describes a curiously pendant portion of the temporal lobe of the brain

which he names "*Polus temporalis inferior*, to distinguish it from the temporal pole of the modern man's brain." On comparing Smith Woodward's two endocranial casts I find that in the second reconstruction this descent is represented as less marked than in the first. In any case it is not based upon an actual cast of this part of the skull, but on a restoration of the sphenoid bone, as the most dependent part of the middle fossa is formed by this bone. On any ordinary endocranial cast a prominence is seen in this position which might be designated a *Polus temporalis inferior*, if one desired to increase the number of poles of the cerebral hemispheres.

The inward slope of the anterior part of the lateral aspect of the temporal lobe of the brain is not peculiar to the Piltdown man. It is a normal character of the brain of modern man (see fig. 9), and I doubt if it were more marked in the Piltdown brain.

There still remains to be noted the eminence on the lateral aspect of the temporal lobe (see dotted line surrounding letter T on fig. 8), to which Elliot Smith appears to attach special importance in connexion with the evolution of the speech centres. This eminence apparently corresponds to a digital impression situated partly on the squamous part of the temporal bone and partly on the adjacent lower portion of the parietal bone. The bevelled upper border of the squamosa has obviously been destroyed, and even on the cranial aspect the two bones do not quite meet, so that in the work of reconstruction this space had to be filled up. This elevation is therefore not entirely an actual cast of the bone fragments, but is partly dependent on the way in which the interval between the two bones is made good, and this would to some extent depend on the angle at which they are set against one another. Although Elliot Smith gives the dimension of this eminence, he does not associate it with any particular convolution, or explain how the "obviously expanding" area of this primitive brain differs from the same region in modern man.

In my Struthers Lecture I directed attention to the variations in the appearance of this region in endocranial casts and showed that prominences indicating the position of the middle and inferior temporal convolutions were of constant occurrence, while the position of the superior temporal convolution often corresponded to a smooth depression on the cast. If the Piltdown endocranial cast be compared with those of modern men in which the brains have been preserved, it will readily be seen that the eminence T corresponds to one of the digital impressions due to the middle temporal convolution. The lateral aspect of this convolution is normally broader and projects farther out than either the superior or inferior temporal convolution, and the greatest transverse diameter of an endocranial cast

is always on an elevated area corresponding to the middle temporal convolution and placed above and generally slightly in front of the external auditory meatus. I think there can be no reasonable doubt but that Smith Woodward's endocranial casts are both correct so far as the general

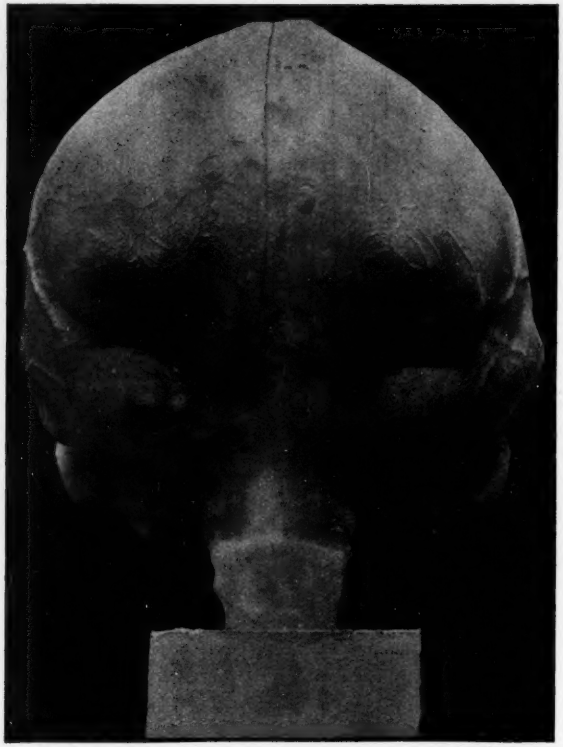


Fig. 9.—Photograph of an endocranial cast of a skull from the New Hebrides, viewed from the front. Note the prominence on the lateral aspect of the temporal lobe and the way in which the surface slopes inwards towards the temporal pole.

position of the elevation marked T in Elliot Smith's figure is concerned, but in the first reconstruction the degree to which it projects laterally as compared with the parietal area is certainly exaggerated.

After a careful study of Smith Woodward's endocranial casts of the Piltdown skull and their comparison with similar casts of modern men in whom the brain was preserved, I have come to the conclusion that the

Piltdown cranial fragments afford no satisfactory evidence in support of the view that any special part of the temporal lobe was either imperfectly or precociously developed.

Elliot Smith also describes the parietal regions and writes:—

"I have already referred to the diminution and flattening of the frontal and parietal regions. In the centre of the latter there is an area, which is well circumscribed by recognisable sulci (*s*, *n*, *k*, *v*, and *o.a.*), raised up into a low hillock, the summit of which is at point marked P. It is more pronounced on the right hemisphere. This indication of the expansion of an area, the large dimensions and fulness of which are especially characteristic of the human brain, is peculiarly significant, when taken in conjunction with a similar condition in the temporal region" (p. 146).

With reference to the diminution in the parietal region, he states that while the maximum breadth of the hemisphere, which is at T, amounts to 130 mm., "at the point P in the parietal region, corresponding to the place where anthropometrists measure the breadth of the brain case, it is only 102 mm." If I understand Elliot Smith correctly, he considers that at the area P the brain, although still imperfectly developed, showed at this low hillock the beginnings of an expansion by which this part of the brain would ultimately attain the large size characteristic of modern man.

It is unnecessary to discuss seriously the evidence in favour of the slight development of this part of the Piltdown brain, because it is based upon the first reconstruction, and Smith Woodward in his second reconstruction has considerably broadened the endocranial cast, increasing the transverse diameter at the level of P by about 15 mm. and making the general form of the upper part of the cerebral hemispheres readily comparable with many existing races.

## General Summary.

It will have been noticed that Dubois, Boule and Anthony, and Elliot Smith have all endeavoured to show from endocranial casts of certain prehistoric skulls that the corresponding brains were of a "primitive" type. Thus Dubois,[1] in describing the endocranial cast of *Pithecanthropus erectus*, writes:—

"The intraparietal fissure is only very partially distinct, but seeming to point to a relatively large occipital lobe, an ape-like condition, undoubtedly consequent on a relatively larger development of the sensory centres of the cortex in contrast with smaller areas of association."

[1] *Op. cit.*, p. 112.

Boule and Anthony,[1] in the case of the La Chapelle man, assert that:

"Si le volume relativement considérable de son encéphale constitue un argument en faveur de son intelligence, l'aspect grossier de toutes les circonvolutions visible paraît au contraire, indiquer des facultés intellectuelles rudimentaires" (p. 193).

Elliot Smith,[2] more decided, writes with regard to the Piltdown brain:—

"Taking all its features into consideration, we must regard this as being the most primitive and most simian brain so far recorded" (p. 147); while Smith Woodward,[3] in a more popular account of this prehistoric man, says:—

"So far as they can be distinguished, the convolutions of the brain are simpler than those of modern man and there are certain parts which remain scarcely more developed than they are in a modern child" (p. 14).

In opposition to these views I venture to assert

1. That the simplicity or complexity of the cerebral fissures and convolutions cannot be determined with any degree of accuracy from endocranial casts, even on complete skulls, much less on reconstructions from imperfect skulls.

2. That it is not possible to estimate, even approximately, from the La Chapelle or Piltdown endocranial cast, the relative degree of development of the various sensory and association centres in the cortex.

3. That the various deductions made by Boule, Anthony, Elliot Smith, and others, with reference to the primitive and simian features of the brains of certain prehistoric men, from an examination of their endocranial casts, are highly speculative and fallacious.

[1] *Op. cit.*, p. 112. [2] *Op. cit.*, p. 112.

[3] *A Guide to the Fossil Remains of Man in the Department of Geology and Palæontology in the British Museum*, 1915.

# THE ARTERIES OF THE PONS AND MEDULLA OBLONGATA.[1]

By J. S. B. Stopford, M.D., *Lecturer in Anatomy, University of Manchester.*

## Introduction.

This investigation was the outcome of an inquiry, made about two years ago, to determine the precise distribution of the bulbar branches of the posterior inferior cerebellar artery.

At first it was intended to work out the exact areas of the hind brain supplied by the individual arteries, by injecting them in a similar manner to that adopted by Beevor (20) in the case of the cerebral arteries; but it soon became apparent that the variation in origin, course, and distribution of the vessels of the hind brain made it an essential part of the work to study also the gross anatomy of these arteries in a large number of brains.

Although the circle of Willis has been repeatedly studied (Windle, Fawcett, etc.) during recent years, little attention has been directed to the exact course and relations of the vertebral and basilar arteries with their branches. No text-book or monograph gives sufficient data, even about the limits of the vertebral artery, and no attempt appears to have been made to determine the percentage occurrence of the common variations in the course of this vessel, or the accurate arrangement of its branches. Even Duret (55), whose work is quoted in references to the blood supply of the bulb and pons, made only twenty injections, and did not determine the modification in the position and size of the areas supplied by the various vessels, which is dependent to a considerable extent upon the slight variations that occur so frequently in their course. Obviously, if this work is to be of any clinical value in localising the position of arterial obstruction, it is essential to determine not only the more usual areas supplied by the vessels but also the variations.

Furthermore, as this part of the work progressed, it became manifest that the variation in the relationship between the arteries and cranial nerves was of considerable clinical importance, and, as this branch of the work has not previously been attempted, I shall have to consider it more fully in a later part of the thesis.

[1] This thesis was submitted for the degree of M.D. at Manchester, in May 1915, and awarded the Gold Medal.

Consequently, it has been found necessary to divide the investigation into three parts:—

1. The gross anatomy of the vessels of the hind brain, with special reference to their bulbar branches and relation to cranial nerves.
   In this section, also, the arrangements of the vessels forming the circle of Willis in the 150 brains examined will be briefly stated.
2. The precise areas of the medulla oblongata and pons supplied by the individual arteries and their branches.
3. The clinical significance of the two former sections, illustrated, as far as possible, by cases.

### Source of Material, Acknowledgments, etc.

Professor G. Elliot Smith has kindly permitted me to make full use of all the material in his department, and I take this opportunity of expressing my heartiest thanks to him both for placing everything possible at my disposal and for his advice, assistance, and constant interest in the work.

The fresh material used for the injection experiments has been obtained from the Pathological Department of the Manchester Royal Infirmary, and I am indebted to Professor A. E. Boycott and Dr W. B. Anderton for their kindness in permitting me to procure such a large number of fresh brains.

For the opportunity of examining and taking notes on the anatomy of the vessels in a number of cases of insanity I desire to thank the Medical Officers of the Prestwich County Asylum.

The photographs used to illustrate the text were reproduced by Mr Gooding, histologist to the Anatomical Department, either from my sketches or the actual specimens. The sketches illustrating Part II. were made directly from the Weigert-stained sections of the hind brain which are the property of the Anatomical Department.

## PART I.

### *THE GROSS ANATOMY OF THE VESSELS AT THE BASE OF THE BRAIN.*

### A.—Those in Relation to the Hind Brain.

The introductory statement explains the necessity for this section. Unless the gross anatomy be considered, no reason for the marked variation in the areas supplied by the individual arteries can be deduced, on account of the lack of accurate information and the disregard by previous observers of the factors which influence this variation in distribution. In addition, it is essential for clinical application to determine the percentage wherever

possible. This was indicated by Gowers (64), who appreciated the fact that variation in the course of the larger trunks entailed a corresponding variation in the origin of the nutrient arteries, and cited this as an explanation of the different clinical pictures which may become manifest as a result of occlusion of one of these trunks. The vessels of 150 brains have been examined, and the series is composed as follows:—

77 from the Pathological Department,
40 from the Dissecting Room,
33 from Prestwich Asylum.

The basal trunks in the latter series show proportionately more anomalies and variations than those of the other two, as suggested by Berkley (22).

No artery has been considered in Parts I. and II. which showed any obvious divergence from the normal as a result of arterio-sclerosis, or other pathological condition of either the vessel or neighbouring structures.

Measurements have been avoided, wherever possible, as the object of Part I. is primarily to elucidate the difficulties of the succeeding one, and to introduce the practical and clinical application of this work, an object which can only be achieved by denoting the various levels in relation to fixed and established points on the hind brain.

In the percentages, decimals have been omitted, and the results in all cases given to the nearest whole number.

### The Vertebral Artery.

After piercing the dura and arachnoid, between the posterior arch of the atlas and the occipital bone, this vessel lies between the most caudal rootlets of the hypoglossal and the uppermost fibres of origin of the first cervical nerve. At this level it is in relation to the lateral aspect of the junction of spinal cord and medulla oblongata, and immediately anterior to the spinal root of the accessory, as that nerve ascends to join its bulbar part. The artery at once turns upwards to pass through the foramen magnum, and, since it also inclines antero-medially as it ascends, comes to lie anterior to the medulla and origin of the hypoglossal nerve. It usually meets the vessel of the opposite side in the region of the antero-median fissure at the lower border of the pons, where the two fuse at an acute angle to form the basilar. During this course the artery is situated in the cisterna cerebello-medullaris, and is only separated from the basi-occipital by the two membranes it has penetrated.

*Size.*—There was almost constantly an inequality in size of the arteries of the two sides (92 per cent.). The left was found to be larger in 51 per

cent. and the right in 41 per cent., the two being of equal calibre in only 8 per cent. In 20 per cent. the discrepancy in size was slight, but in the rest (72 per cent.) the difference was marked, and in twenty-two the vessel of one side was at least twice as large as that of the other.

| | | | | | |
|---|---|---|---|---|---|
| The left was approximately twice the size of the right in 1 case. | | | | | |
| „ | „ | three times | „ | „ | 2 cases. |
| „ | „ | four „ | „ | „ | 2 „ |
| „ | „ | six „ | „ | „ | 3 „ |
| „ | „ | eight „ | „ | „ | 3 „ |
| The right was approximately twice the size of the left in 1 case. | | | | | |
| „ | „ | three times | „ | „ | 4 cases. |
| „ | „ | four „ | „ | „ | 3 „ |
| „ | „ | six „ | „ | „ | 1 case. |
| „ | „ | eight „ | „ | „ | 1 „ |
| „ | „ | twenty „ | „ | „ | 1 „ |

The right vertebral was excessively small in five cases, and both were minute in one case; Blackburn (25) found the right abnormally small in 9 per cent., the left in 5 per cent., and both in 1 per cent.

It is generally admitted that the left is the larger, and Table I. gives the results of the various observers who have investigated this point.

The great variation in the figures is probably due to the fact that many have considered "equal" those cases in which the difference in size on the two sides was only slight.

Table I.

| Observer. | Number Examined. | Size. | | |
|---|---|---|---|---|
| | | Left Larger. | Right Larger. | Equal. |
| | | per cent. | per cent. | per cent. |
| Ehrman (56) | 57 | 16 | 14 | 70 |
| Mori (99) | 35 | 20 | 2 | 78 |
| Loewenfeld (92) | 61 | 39 | 51 | 10 |
| Davy (43) | 98 | 27 | 8 | 65 |
| Longo (90) | 50 | 6 | 6 | 88 |
| Stopford | 150 | 51 | 41 | 8 |

Lewis (160) carefully measured the diameter of the vertebral artery on the two sides, in the brains of 45 lunatics, and found the average on the left to be 3·42 mm., and on the right 3·147 mm. It is curious that practi-

cally no attention has been paid to the varying calibre of the individual vessel of either side, since so many have investigated the comparative size of the two. The present research has shown that there may be a very marked reduction in size at three points in that part of the course of the vessel which is under consideration. In fully half the cases there was a distinct diminution in diameter immediately after the vessel had pierced the dura; a second narrowing was to be found at the upper limit of its course above the origin of the anterior spinal, where the lumen was usually smaller than anywhere. The third point of notable reduction in size about midway between the other two was rare, being only found four times on each side, but is clinically of equal importance as a possible site of an embolus; and in this connexion it is of interest to note that the point of reduction in calibre in two of these four cases marked the level of the origin of the posterior inferior cerebellar artery, which in each case was unusually large and almost equal in size to the vertebral.

*Site of Junction to form the Basilar.*—Without exception, the modern text-books describe the lowest limit of the basilar as the lower border of the pons, and Spalteholz (126) alone gives some indication that the level of the termination of the vertebral arteries may vary, by stating that the posterior margin of the pons is "approximately" the site of the formation of the basilar. In older treatises on anatomy opinion is more divided with regard to the upper limit of the vertebral arteries; Ruysch (117) pictures the lower limit of the basilar as some distance above the lower border of the pons, and Bourgery (159) as slightly below, whilst Willis (155), Vicq d'Azyr (147), and several others represent it approximately at the lower border.

Weber (151) quotes a case of union of the vertebral arteries at a lower level than normal.

In this series the vertebral arteries were found to fuse at the lower border of the pons in 48 per cent., above that point in 20 per cent., and below in 32 per cent. As the variation, above or below, was slight in a number of cases, and was proved not to affect the distribution as it does when more considerable variation exists, it may be said that the junction was approximately *at* the lower border of pons in 73 per cent., *above* in 8 per cent., and *below* in 19 per cent. It was never found higher than a third of an inch above the more usual site; but below, it was found as far caudally as the level of the lower extremity of the olivary eminence in one case, and the mid-olivary region in five others.

*Anomalies.*—In two instances the right vertebral divided into two trunks for the greater part of its intracranial course:—

In No. 20 (fig. 1), immediately after piercing the dura mater, the

vessel bifurcated into equal branches which united again a quarter of an inch below the pons, so that an aperture fully one inch long was formed which transmitted all the rootlets of the right hypoglossal nerve.

In No. 114 (fig. 1) the right vertebral exhibited duplication between similar limits, but in this case the lateral division was larger than the medial, and both parts were anterior to the superficial origin of the XIIth nerve.

It is curious that such an extremely rare anomaly should occur twice in this series. Tarenetzky (136) recorded one case precisely similar to

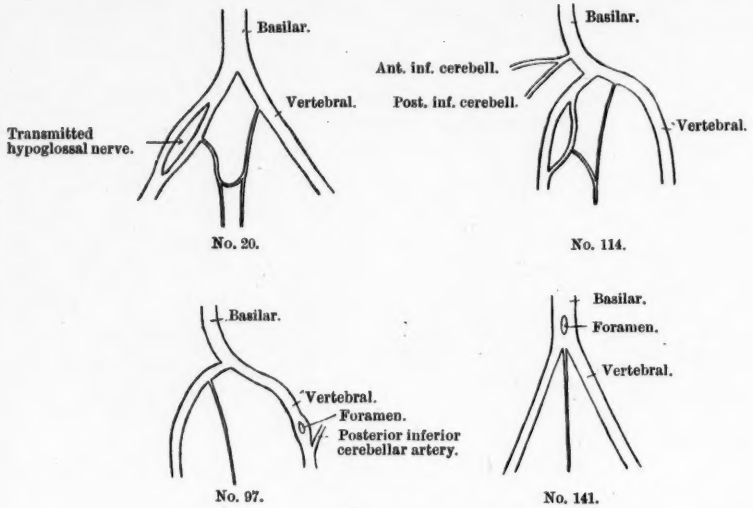



FIG. 1.—Anomalies of vertebfal and basilar arteries.

No. 20; and Kadyi has reported another in which the vertebral divided into two before piercing the dura: one trunk followed the normal course and united with the other branch (which entered the spinal canal with the second cervical nerve) within the cranium.

Ogle (103) described a case where one of the roots of the left hypoglossal nerve completely pierced the wall of a normal left vertebral; and Anderson (6) has given an account of duplication in the lower part of the neck below the level of the third cervical vertebra.

The only other anomaly was found in No. 97, where a minute foramen (sufficiently large to admit a probe) was seen penetrating the centre of the left vertebral just above the origin of the posterior inferior cerebellar

artery. A similar condition has been described by Blackburn (25) in the case of the basilar, and indications of this anomaly in other vessels will be referred to subsequently, but no previous record of its occurrence in the vertebral is to be found.

Reference to the literature makes it clear that anomalies in this part of the course of the vertebral are of considerable rarity. Robinson (112) mentions the possible absence of the upper end of the vertebral, and Berry and Anderson (24) and Batujeff (13) have each described a case of failure of union of the two vessels, with consequent abnormal origin of the basilar.

*Branches of the Vertebral Artery.*

I. *Bulbar.*

No attempt has previously been made to investigate this group of branches.

They may be conveniently divided into three sets:—

A. An *upper set*, arising from the dorsal aspect of the vessel just caudal to its termination. They are most numerous in cases where the anterior spinal arises at an unusually low level, and then compensate for the deficient distribution of the latter vessel. Occasionally they are absent. When present they enter the substance of the bulb either in the antero-median or antero-lateral fissures, or else in the groove marking the junction of medulla and pons, in which position they are usually accompanied by bulbar branches from the lower end of the basilar.

B. An *intermediate set*, arising from the lateral aspect of the vertebral, about the mid-olivary region, and entering the medulla through the postero-lateral fissure.

They are very variable in size and number, and are quite frequently absent; as I have previously (30) pointed out, this variability is largely dependent upon the course and distribution to the bulb of the posterior inferior cerebellar artery.

C. A *lower set*, consisting usually of one moderately large branch, which arises from the medial aspect of the vertebral, whilst it is in relation to the lateral aspect of the medulla, and at once breaks up into a number of fine twigs, which enter the lower part of the bulb. This has been very constantly found in cases where a sufficient length of the vertebral has been removed with the brain; but it is liable to be missed by an incomplete removal of this vessel, and this is probably the reason why it seems to have been invariably omitted in previous descriptions.

II. *The Anterior Spinal Artery.*

This artery normally arises by two delicate branches, one from the medial side and upper part of each vertebral, which unite on the pyramids below to form one median branch, or else continue as two separate vessels after anastomosing. Their continuation down the ventral aspect of the spinal cord is maintained by reinforcements from various arteries at different levels. The relative position of the reinforcing arteries and other structures which pass through the intervertebral foramina has recently been studied by Swanberg (135), who has found that the vessels are imbedded in the fat which surrounds and protects the nervous elements.

The right branch of origin was found to be absent in 9 per cent., the left branch in 3 per cent., and the vessel arose by one stem from the angle formed by the junction of the two vertebrals in 3 per cent., as pictured by Willis (155).

In the cases where the vessel exhibited the more usual double origin, the right was slightly larger in 43 per cent. and the left in 46 per cent., the two being approximately of equal calibre in 11 per cent. In two instances (Nos. 28 and 147) the left branch had a double origin, and this was seen on the right side in one specimen (No. 65).

The origin in 51 per cent. on the right and 59 per cent. on the left was from the extreme upper part of the vertebral (*i.e.* in the region of the cephalic extremity of the olivary eminence); in 29 per cent. on the right and 28 per cent. on the left the origin was about the level of the mid-olivary region, and in 20 per cent. on the right and 13 per cent. on the left it was at the level of the caudal extremity of, or slightly below, the olive. The low origin of these branches did not appear to depend upon the junction of the two vertebral arteries occurring at a lower level than usual, because in the majority the basilar was formed at the lower border of the pons, or even above that level. The site of the origin of the anterior spinal is an important factor in influencing the area of the medulla supplied by the vertebral, and will be dealt with again more fully in the next section.

In 6 per cent. the right and left branches of origin remained separate, but in the remainder there were one or more transverse communications between the two, or else they fused to form one median vessel—the two alternatives occurred in exactly equal proportion (47 per cent.). The site of the communication or fusion was about the level of the lower end of the olive in 63 per cent., and almost at the junction of the bulb and spinal cord in 31 per cent., the latter level being the one more frequently found in the standard text-books. In the remaining 6 per cent. the two vessels continued their course without any anastomosis, as previously stated.

*Anomalies.*—Some variation in disposition was commonly found near

the origin, but this has apparently no influence upon the distribution, and reference to fig. 2 will make clear the variations met with in this series.

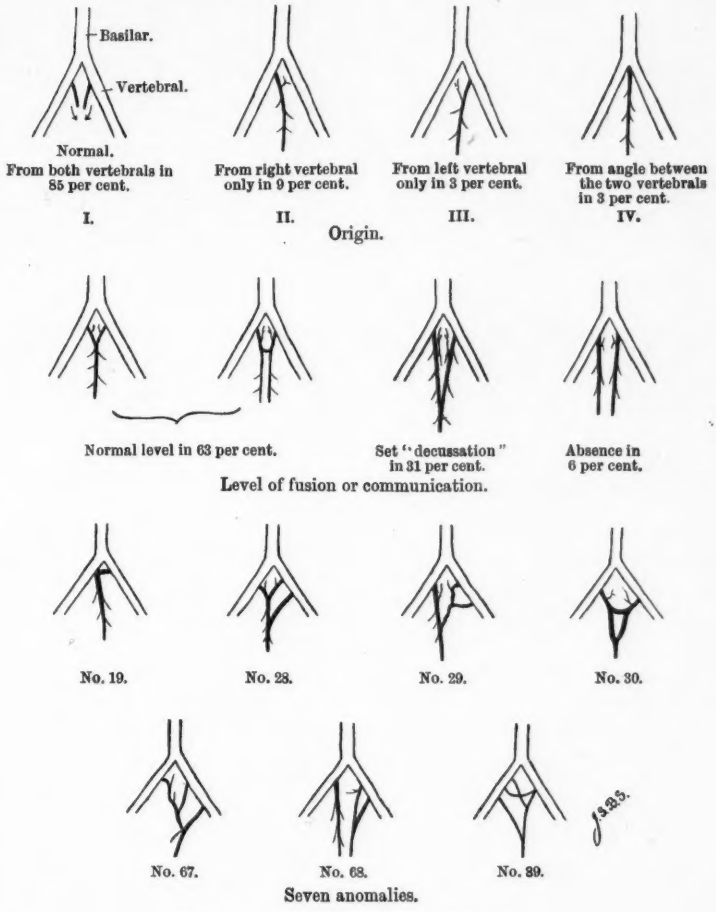



FIG. 2.—Variations of anterior spinal artery.

The *bulbar branches* of the anterior spinal may be divided into three sets:—

A. A set of branches arising from the right and left stems before fusion or communication. These break up, forming a fine network, on

the upper part of the pyramids in which their terminal filaments end. A few filaments penetrate the upper part of the antero-median fissure.

B. Branches which spring from the median vessel (or vessels) after fusion and pass directly into the antero-median fissure. This group, especially in the case of the cord, has been studied by Adamkiewicz (3) and Kadyi (82).

C. Branches from the same origin as the last which pass laterally on the pyramids, like the transverse pontine branches of the basilar, and after repeated division penetrate the pyramids or the antero-lateral sulcus. When the branch of origin of one side is absent its bulbar supply is invariably furnished by the vertebral.

III. *The Posterior Inferior Cerebellar Artery.*

The descriptions of this vessel vary within the most extreme limits. The vaguest references are generally made to its course and origin, although in recent years its precise anatomy has become of the greatest value, on account of the well-recognised group of symptoms which its occlusion produces. Robinson (112), Walsham (149), and Piersol (108) describe it as arising from the upper part of the vertebral; and almost all the text-books picture or describe it as passing more or less directly backwards around the bulb. Cruveilhier (38) gives some indication of its course when he says: "en décrivant des flexuosités remarquables autour du bulbe rachidien"; and of more recent writers Charpy (34) gives the most complete account, which is largely based on Duret's researches; whilst Wallenberg (148) has studied it more especially from a clinical standpoint. In a recent paper (30) I have attempted to give its course more accurately, and to demonstrate the influence of variation of this upon its distribution.

The posterior inferior cerebellar artery is much the largest branch of the vertebral—in three cases it was larger than the parent vessel on the right side in this series—and arises from its lateral side about the lower end of the olive. After curving round the lower border of the olive it ascends in the neighbourhood of the postero-lateral sulcus, usually posterior to the fila of the vagus and glossopharyngeal nerves, almost to the lower border of the pons, where it changes its direction and forms a loop with its convexity toward the pons. It now proceeds downwards, with a slight inclination toward the mid-dorsal line, on the restiform body and the other infero-lateral boundaries of the fourth ventricle, to just below the calamus scriptorius, where it turns outward on to the vallecula to divide into its fully described lateral and medial branches for the supply of the inferior surface of the cerebellum. In this manner the vessel makes a

loop with its convexity toward the pons on the lateral aspect of the upper part of the bulb, the ascending and more anterior limb being shorter and in relation to the postero-lateral sulcus, whilst the posterior and longer limb is in relation to the lateral wall of the fourth ventricle.

For clinical application it is necessary to realise that there is a free anastomosis on the surface of the cerebellum between the three cerebellar arteries.

The artery has been found to vary considerably in size and course even on the two sides, as many have previously noticed.

*Size.*—The two vessels were of equal size in 22 per cent., the right and

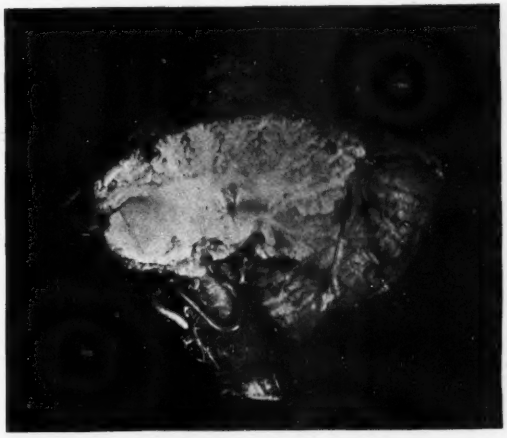


FIG. 3.—Course of posterior inferior cerebellar artery.

left were each larger in 39 per cent. In one case the left was four times the size of the right, and in another three times as large, whilst in three specimens the right was larger than the vertebral, which was unusually small, especially above the origin of this branch.

The *origin* described above as normal was found in 68 per cent. on the right side and 74 per cent. on the left. In 12 per cent. on the right and 9 per cent. on the left it arose slightly above this point, and in 17 per cent. on both sides its origin was considerably below the olive, just cephalic to the point where the vertebral artery pierced the arachnoid. In 3 per cent. on the right side it sprang from the vertebral at its termination, just before it joined with the opposing one to form the basilar.

Its *course* followed precisely that described as normal in 58 per cent.

on the right side and 49 per cent. on the left; but in 6 per cent. on the right and 19 per cent. on the left the convexity of the loop only ascended as high as the mid-olivary region. As this minor variation will be seen not to affect the distribution, for practical purposes it may be stated that the more usual course is found in 64 per cent. on the right and 68 per cent. on the left. In 5 per cent. on the right and 4 per cent. on the left the vessel failed to form any loop, and curved almost directly backward to the calamus region. In the final group the artery curved backward and caudally to the spinal cord or directly outward on to the cerebellum; in either case it usually failed to provide any bulbar branches; this configuration was found in 31 per cent. on the right and 29 per cent. on the left, and is curiously the one most in accordance with the standard descriptions.

*Absence.*—This artery is not infrequently absent, and was found wanting on the right side in 15 per cent., on the left in 6 per cent., and on both sides in 3 per cent. Blackburn (25) found the right absent in 5 per cent. and the left in 3 per cent. When absent, the bulbar branches are almost invariably supplied by the vertebral, but in one of the above cases the anterior inferior cerebellar artery provided branches for the postero-lateral sulcus, whilst in another the internal auditory artery compensated for the deficiency. The cerebellar branches were found to be replaced by the anterior inferior cerebellar in all cases of absence.

*Anomalies.*—An abnormal origin was noted three times, and in each case it was on the right side.

In Nos. 89 and 131 the artery arose from the lowest limit of the basilar, in the latter case in common with the anterior inferior cerebellar. Longo (90) found both posterior cerebellar arteries, on each side, arising from the basilar in one case in his series of fifty.

In No. 24 it had a double origin from the right vertebral, the lower one at the usual level and the upper one at the mid-olivary region; the two roots embraced a few fila of the hypoglossal as they converged to form the main arterial trunk.

In No. 137 a small foramen, exactly comparable to the one described in connexion with the vertebral, was found in the artery of the left side. Twice on the right, and in a similar number on the left, the vessel had a somewhat unusual course, as it proceeded to the dorsal surface of the bulb and then ascended at the side of the fourth ventricle up to the pons before passing on to the cerebellum, thus forming a loop in the reverse direction.

### *Branches.*

The most important and interesting are those which supply the medulla oblongata.

A. *Bulbar.*—Branches are supplied to the bulb by both limbs. The ascending limb provides between two and seven minute branches to the region of the postero-lateral sulcus, whilst the descending limb supplies a variable number of branches to the region of the medulla, with which it comes into relation. Frequently the latter group of branches is entirely absent.

B. *Cerebellar.*—The medial and lateral terminal branches have been seen to anastomose freely with the other cerebellar arteries, but they have not been studied in any detail.

C. The *Choroidal* branch to the plexus of the fourth ventricle has not been fully studied, but in a large number of specimens used for injection it was found to arise from the upper limit of the loop in the region of the cerebello-pontine angle.

D. The *posterior spinal* in this series has been found to be more frequently a branch of this vessel than of the vertebral, as discussed in the succeeding paragraph.

IV. *The Posterior Spinal Artery.*

This artery has been included as one of the branches of the vertebral, because that is the origin most frequently stated, but it is not in accordance with the findings in this investigation. Duret (55) and Dana (41) describe its origin as from the posterior inferior cerebellar, but others give the vertebral, although Henle (72) and Vicq d'Azyr state that it sometimes arises from the other vessel.

Unfortunately this artery was found intact in a much smaller proportion of specimens than was the case with any of the others, and consequently the percentages cannot be so accurate or valuable. Nevertheless, the figures are sufficiently convincing to be of assistance in the determination of the question of origin.

On both sides it arose from the posterior inferior cerebellar in 73 per cent., and on the right side it sprang from the vertebral in 18 per cent., and from the same artery on the left in 20 per cent.

In 9 per cent. on the right and 7 per cent. on the left it had a double origin, being in communication with both the vertebral and the posterior inferior cerebellar artery.

It was seen to arise most commonly from the posterior inferior cerebellar artery just before the latter vessel extended to the cerebellum; and almost at once divided into an ascending ramus, which proceeded upward on the posterior columns to the region of the calamus scriptorius, and a descending ramus, which passed downward behind the posterior roots, to be reinforced in a manner similar to the anterior spinal.

The vessel was absent on one or both sides in a large percentage of cases, but it is quite impossible to give any reliable figures.

The ascending ramus was also very inconstant.

Numerous minute bulbar branches are given by both rami, when present, to the posterior columns and their nuclei.

### The Basilar Artery.

The basilar artery, formed by the junction of the two vertebrals, extends from the caudal to the cephalic borders of the pons in the cisterna pontis. It lies on the ventral aspect in the median groove, which is produced by the prominences formed on each side by the pyramidal fibres and not by the pressure of the vessel, as may be demonstrated by the presence of this groove in cases where the basilar is deflected some distance from the median plane. It is only separated from the basisphenoid by the arachnoid and dura.

The *origin* has been considered in the references to the level of the junction of the vertebral arteries. In four instances the basilar appeared to be formed almost entirely by the right vertebral, and in a similar number by the left; this was the result of the great discrepancy in size between the two vertebrals in these cases.

*Size.*—At its origin the vessel is almost invariably larger than either vertebral, but there is a gradual and apparent diminution in size as it is traced to its termination. In three specimens there was an unusually marked and rapid reduction in calibre.

*Termination.*—Normally the artery ends at the upper border of the pons by dividing into the two posterior cerebrals. In two cases this division was just below the upper border, and in two others it was fully half an inch below.

The basilar has been found to follow a more constant course than any other vessel studied in this series, and at the same time it has been seen to exhibit manifestation of arterial disease much more frequently than the others.

*Anomaly.*—No. 141 showed a small foramen immediately above the origin, exactly similar to that once described in the case of the vertebral and posterior inferior cerebellar arteries.

Foramina have also been noted in this vessel by Blackburn (25), Longo (90), and Rendall (111).

The only other abnormalities of the basilar which have ever been reported are:—

(1) The presence of a median septum in the interior denoting incomplete fusion during development, which has been noted by Blackburn and many others.

(2) The presence of a band which traverses the lumen in a transverse direction; this was seen seventeen times in ninety-eight autopsies by Davy (43).

(3) The presence of a communicating branch, generally of considerable size, between the internal carotid and the basilar, as reported by Elliot Smith (124), Decker (45), Incoranto (79), Duret (54), and Blackburn (25).

No attempt has been made to search for the former two anomalies, as it would have damaged the vessels too severely to permit the injections to be performed later.

From De Vriese's (49) work on the ontogeny of the basilar, and Beddard's (16, 17, and 18) studies of the arteries at the base of the brain in other vertebrates, it is easy to explain all the anomalies of this vessel, as they appear without exception to indicate its formation from the two most caudal branches of the internal carotid.

*Branches.*

I. *Pontine.*

These may be divided, according to course and disposition, into two sets:—

A. A *median* set, composed of minute branches arising from that surface of the basilar lying in contact with the pons, which at once enter the substance of the brain along the median groove. Duret (55) subdivided this set into three groups, but no advantage can be gained by this; nor did my own observations justify it. Certainly they are more numerous caudally, where many enter the sulcus between the pons and bulb together with branches from the vertebrals, and again at the cephalic extremity of the basilar; but between these points they are generally found continuously, with no suggestion of any definite grouping.

B. A set of *transverse* rami which extend laterally and subdivide as they proceed into smaller branches which penetrate the ventral surface of the pons at right angles to the parent vessel. These vessels were generally arranged symmetrically on the two sides, but were variable in size and number. Normally an unusually large branch was seen to extend to the trigeminal nerve, which it supplied in a similar manner to the "radicular" arteries of Duret. If the meninges and vessels were removed, small orifices for the entrance of these vessels could be seen on the surface between the superficial transverse pontine fibres.

From embryological research and comparative study there is good reason to conclude that these transverse rami are arranged segmentally.

II. *The Anterior Inferior Cerebellar Artery.*

This vessel normally passes laterally, and somewhat caudally, from its origin over the ventral surface of the pons towards the cerebellar hemisphere of its own side, on to the anterior part of the inferior surface of which it extends to anastomose with the posterior inferior cerebellar. In the region of the cerebello-pontine angle it almost invariably passes between the pons and the facial and auditory nerves, close to their superficial origin. In two cases (Nos. 27 and 65), the vessel formed a complete arterial loop around these two nerves before it approached the inferior surface of the cerebellum. In one case the vessel was double on both sides. Blackburn discovered this eight times in 220 examinations.

The size and course of this vessel and the level of its origin from the basilar are variable even on the two sides; the variation in the former two depends largely upon the size and distribution of the posterior inferior cerebellar.

The left was *absent* on two occasions, but both in only one case (No. 131).

*Size.*—The arteries on the two sides were equal in calibre in 15 per cent., the right was larger in 48 per cent., and the left in 37 per cent. In six the right was very considerably larger than the left.

*Origin.*—In 85 per cent. the two were seen to arise at the same level; of these 78 per cent. arose from the lower third, 17 per cent. from the middle, and 5 per cent. from the lower limit of the basilar.

Including the 15 per cent. where the vessels of the two sides gained origin at different levels, it may be said that:—

| | Right. | Left. |
|---|---|---|
| Origin was from lower third of basilar in | 75 per cent. | 73 per cent. |
| „ „ middle „ | 16 „ | 21 „ |
| „ „ lower limit „ | 9 „ | 6 „ |

On the right side the artery was found to arise from the vertebral twice and on the left side once.

In one case, on the right, the vessel had a common origin with the posterior inferior cerebellar from the lower end of the basilar; this has been previously noted by other observers several times.

*Relation to the Abducent Nerve.*—At the present time this neurovascular relation is clinically of very considerable interest; yet our anatomical knowledge of the subject is unfortunately incomplete and far from satisfactory.

The only previous investigation of this relation was made by Cushing (40), and his conclusions were based on only fifty-nine observations. As he failed to differentiate between the relations of the anterior inferior cerebellar and the internal auditory arteries, no object can be served by comparing his results.

Only two treatises—those of Charpy (34) and Cruveilhier (38)—on anatomy refer in the text to this relationship. Both describe the artery as lying sometimes ventrally and sometimes dorsally to the nerve, but omit any reference to the frequency of the occurrence of either. Bardeleben (9), Howden (74), Macalister (93), Rauber (110), Robinson (112), Sappey (118), Spalteholz (126), Thane (139), Toldt (142), Vicq d'Azyr (147), and Antonius and Caldani (7) all picture the artery as ventral to the nerve; whereas Turner (144), Walsham (149), Deaver (44), and Charpy (34) illustrate the reverse, although only the latter makes any reference in the text.

The present investigation has shown the artery ventral on both sides in 74 per cent., and dorsal in 8 per cent., and there is a difference in this neuro-vascular relationship on the two sides in 18 per cent.

Taking all into account, the right was ventral in 86 per cent. and dorsal in 14 per cent., whilst the left was ventral in 81 per cent. and dorsal in 19 per cent.

It is necessary at this point to realise that when the artery lies in the dorsal position, the abducent nerve may be compressed against the basi-sphenoid by the vessel, as the former structure proceeds toward the cavernous sinus.

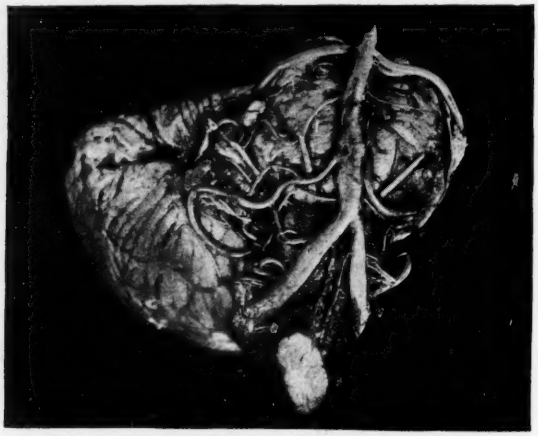
In five cases on the right and three on the left the artery was too far forward to bear any relation to the nerve.

*Anomalies.*—Absence and the irregular origin from the vertebral have been referred to previously. The only other anomaly met with was perforation of the abducent by the artery, a condition which occurred twice (Nos. 116 and 137) in this series, and in each case was on the left side. Nearly three years ago this condition was noted on both sides in a specimen in our own dissecting room by Mr T. P. Kilner, formerly a Demonstrator of Anatomy in this Department, but this has not been included in the 150 brains described. Valenti (145) first observed this abnormal relation, and more recently Cushing (40) discovered it three times in fifty-nine brains, and in each case it was on the left side.

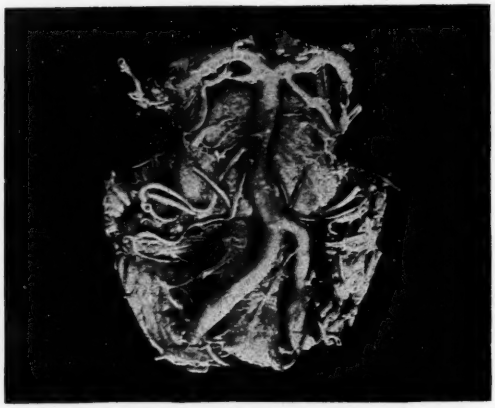
Consequently in the six examples cited above, it was present five times on the left only and once it was bilateral.

No effort appears previously to have been made to elucidate or explain the etiology of this anomaly; but, in the light of the researches of

Belogolowy (21) in the chick, and Bremer (28) and Elze (58) in the human embryo, it is not difficult to appreciate the cause of its presence.



A. Artery ventral.



B. Artery dorsal.

FIG. 4.—Relative position of VIth nerve and anterior inferior cerebellar artery.

The above researches have shown that the abducent originally arises by many roots which are arranged segmentally. Normally in man the intermediate ones alone remain, but persistence of the others may occur and

constitute aberrant roots, which have been fully described by Bremer. Between these segmentally arranged roots transverse branches of the basilar have been seen by Elze and Bremer; from this it would appear likely that, in cases of perforation of the VIth nerve, the anterior inferior cerebellar passes between the true root and an aberrant one.

A very complete bibliography of the morphology of the abducent and other nerves supplying the eye muscles has been given by Neal (101).

This emphasises Cunningham's (39) statement—"Nerves are the most conservative of all structures which go to build up the human body. They

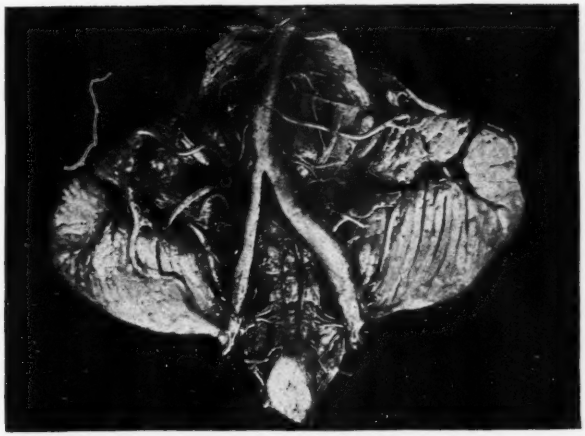


FIG. 4.—C. "Splitting" of nerve on left by artery.

cling most tenaciously to old traditions, and travel most pertinaciously along the old beaten paths."

It is interesting to notice that the plates of many of the older writers (Vicq d'Azyr, Caldani, etc.) represent the abducent as formed by two distinct roots, of which the more medial is smaller.

*Branches.*

A. *Pontine.*—A few branches were given to the more caudal and lateral part of the pons, in a similar manner to the perforating rami of the transverse pontine branches of the basilar.

B. *Bulbar.*—In a few cases small branches were given to the upper part of the postero-lateral sulcus, when this region was incompletely supplied by the posterior inferior cerebellar. Quite frequently branches enter the sulcus between the pons and the bulb.

C. *Internal Auditory.*—Full reference will be made to the origin of this artery in the next paragraph.

D. *Cerebellar.*—Chiefly destined for the supply of the inferior surface of the cerebellum together with the posterior inferior cerebellar artery.

III. *The Internal Auditory Artery.*

The presence of this artery was somewhat inconstant, but no accurate percentage could be given owing to the frequency with which it is damaged in the removal of the brain. As a branch of the basilar, it is undoubtedly more frequently absent than present.

It is customary to describe it as arising from the basilar and as passing laterally and slightly caudally to reach the auditory nerve, which it accompanies into the internal auditory meatus.

*Origin.*—The conclusion drawn from this examination is that it arises more frequently from the anterior inferior cerebellar than the basilar, as in 64 per cent. on the right and 62 per cent. on the left it was given off by the former artery. It is usually seen to arise at the point where the anterior inferior cerebellar leaves the brachium pontis and extends on to the cerebellum, a point where the artery is in close relationship with the auditory and facial nerves.

In 13 per cent. on the right and 10 per cent. on the left it was seen to spring from the basilar immediately above its origin, in 20 per cent. on the right and 18 per cent. on the left it came off from the junction of lower and middle thirds, and in 3 per cent. on the right and 10 per cent. on the left it was derived from about the middle.

*Size.*—It is generally quite small, but in one case it was unusually large. The vessels of the two sides were equal in size in 15 per cent., in 50 per cent. the right was larger, and in 35 per cent. the left.

*Relation with Abducent Nerve.*—Clinically this relation cannot be so important as that in the case of the anterior inferior cerebellar. In the first place, on account of its diminutive size, the risk of compression or strangulation of the VIth nerve must be materially reduced even in those cases where it does arise from the basilar (36 per cent. on the right and 38 per cent. on the left); and secondly, its frequent origin from the anterior inferior cerebellar prevents the possibility of any intimate relation between the two structures occurring in 64 per cent. on the right and 62 per cent. on the left. In those cases where this neuro-vascular relation could be considered, it was found that the artery passed dorsal to the nerve in 10 per cent. on the right and 16 per cent. on the left. In one of these, on the left, the artery arose from the anterior inferior cerebellar on the

medial side of the nerve; but in every other case the origin from this artery was lateral to the nerve and generally at the point previously described, so that the two were never intimately related to each other. It is of interest to notice that both the internal auditory and the anterior inferior cerebellar arteries take the dorsal course more frequently on the left. *Both* these arteries were seen to pass dorsally in the same specimen on the right side in 6 per cent., never on the left alone, and only in one instance on both sides. Cushing (40) states that sometimes both arteries may be dorsal on one side, but it is unusual to find it on both sides, and these figures support that supposition.

*Branches.*

A. The main vessel supplies the auditory nerve and the internal ear.
B. Occasionally a few bulbar, pontine, or cerebellar branches are to be seen.

IV. *The Superior Cerebellar Artery.*

The presence, origin, and course of this artery were all found to be very constant.

It arises from the basilar, close to the point where it bifurcates to form the posterior cerebral arteries, and, after extending laterally immediately caudal to the oculomotor nerve, curves round the crus cerebri to gain the superior surface of the cerebellar hemisphere of its own side. On the surface of the cerebellum it divides into numerous branches, which freely anastomose with the other cerebellar arteries. The injection experiments have proved that there is quite a free communication between the cerebellar arteries of the two sides, and this anastomosis must be an important factor in preventing softening of the cerebellum in many cases of occlusion of one or more of these arteries.

In the case of the cerebral arteries a similar anastomosis was found by Beevor (19) to exist in the pia mater.

*Size.*—The arteries of the two sides were of equal size in 33 per cent., in 31 per cent. the right was larger and in 36 per cent. the left.

Diminutive size, or absence, of one or other cerebellar artery is invariably provided for by an increase in calibre of one of the others, so that there appears to be a compensatory provision for the supply of a more or less definite volume of blood to the cerebellum.

The *origin*, as stated, was found to be very constant. In 94 per cent. it was at the upper limit of the basilar, practically at the upper border of the pons, just caudal to the point where it divided into the posterior cerebral arteries. In 6 per cent. the origin was slightly caudal to this

point, so that the relationship to the oculomotor nerve was more remote. In one case the right superior cerebellar sprang from the basilar at the junction of its upper and middle thirds.

The vessel was only *absent* once, and then only on the left side, when is was replaced by branches from the posterior cerebral. Longo (90) quotes a similar example, but Blackburn (25) found the vessel constantly represented in the 220 he examined.

*Duplication.*—The vessel was found to be double in a large number of cases; in 12 per cent. the right only, 16 per cent. the left only, and 3 per cent. on both sides. Once on the left it was represented by three vessels. Blackburn found it duplicated on the right only in 2 per cent., left only in 1 per cent., and on both sides in 1 per cent. In about 4 per cent., on each side, the artery was found to divide into two immediately distal to its origin.

The explanation of duplication of the cerebellar vessels necessitates only a passing reference to Mall's (94) research on the development of the intracranial blood-vessels, by which he proved that the cerebellar arteries are represented primarily by a cluster of branches, but later become reduced to a single vessel. Persistence of more than one of these branches will result in duplication, and similarly the explanation of double origin, as described in the case of one posterior inferior cerebellar artery, becomes clear. In a previous paper (134) I discussed the anomalies of the renal and spermatic vessels, and many of the opinions expressed there may be applied to the present question.

*Branches.*

A. *Pontine*.—The artery was found to give frequently a few irregular branches to the pons as it extended laterally from its origin.

B. *Mesencephalic.*—These have not been studied, as they were very fully described by Alezais and d'Astros (5).

C. *Cerebellar.*—Destined chiefly for the supply of the superior surface of the cerebellum.

V. *The Posterior Cerebellar Artery.*

This branch of the basilar will be briefly referred to in the section on the arteries forming the circle of Willis. The two vessels at their origin form approximately an angle of 90°.

## B.—The Circulus Arteriosus (Willisii).

This significant anastomosis, between the intracranial branches of the internal carotid and basilar arteries, is situated in the cisterna inter-

peduncularis. It has been very systematically and extensively studied by many observers, which was to be expected in view of its great anatomical, physiological, medical, surgical, and even pathological interest. The more recent and extensive investigations have been performed by Blackburn (25), Windle (157), Fawcett and Blackford (59), De Vriese (50), and Longo (90), in man, and by Beddard (16, 17, and 18) in other mammals.

My own observations on this arterial circle will be briefly stated and then tabulated, together with those most recently made (see Table II.).

All the vessels comprising the circle of Willis were intact in 105 specimens, and there was a complete circular anastomosis in 98 (93 per cent.) of these, the deficiency in six of the remainder being due to the absence of the posterior communicating on one or the other side. One would expect this to be the vessel most frequently absent, because its importance is relatively much greater during the early weeks of intra-uterine life, when it represents the origin of the posterior cerebral from the internal carotid, than later, when the posterior cerebral is reinforced by anastomosis with the basilar and the posterior communicating is no longer essential for the maintenance of the blood supply of the posterior part of the cerebrum. Consequently, the posterior cerebral normally transfers its origin from the internal carotid to the basilar, with the result that the posterior communicating attains its maximum functional importance very early, but soon loses it, owing to the development of the anastomosis between the posterior cerebral and the basilar; and from that time onward fails to increase in size at the same rate as the other arteries. In cases where the anastomosis between the posterior cerebral and basilar is feeble and insufficient, the posterior communicating does not lose its function but persists as the main channel of supply to the main trunk of the posterior cerebral. Under these circumstances the posterior communicating is frequently larger than the origin of the posterior cerebral from the basilar, and the latter in consequence appears to be a branch of the internal carotid. That is to say, what appears in the adult to be a compensatory enlargement of the posterior communicating, to accommodate for its abnormally small origin from the basilar, is, strictly speaking, a persistence of the embryonic condition. Clinically, one would expect, even momentary, obstruction of the internal carotid in these cases to manifest more widespread and alarming symptoms than cases where the circle of Willis conformed to the more normal arrangement. The seventh instance of an incomplete circle illustrates perfectly the embryonic condition, because it represents complete failure of development of the anastomosis between the basilar and the posterior cerebral, and consequently in this case the latter vessel is a true branch of the internal carotid.

### The Posterior Cerebral Artery.

As is to be expected from the above account, the size of the origin of this vessel from the basilar was inversely proportionate to the size of the posterior communicating in all (except one case).

The size of the origin of the arteries of the two sides was equal in 32 per cent., the right was larger in 36 per cent., and the left in 32 per cent. No observer has previously determined the relative sizes of the two at their origin, although clinically this must be the most important point. The artery appeared to arise chiefly from the internal carotid, on both sides in 2 per cent., the right only in 5 per cent., and the left side only in 3 per cent.

In No. 41 the posterior cerebral sprang from the internal carotid alone, owing to the failure of its normal post-fœtal origin from the basilar.

In No. 73 the vessel was double, the supernumerary ramus being a branch of the posterior communicating. Shaw (125) described two examples of duplication of this artery, one on the right side and one on the left; both consisted of a double origin from the basilar, and in both the two branches united immediately after junction with the posterior communicating. Reduplication of this artery is apparently extremely rare, as there are no other records of such an occurrence.

In No. 120, as previously indicated, the left posterior cerebral provided the superior cerebellar of that side. Normally the artery passes anterior to the oculomotor nerve, but it is only in actual contact in about 50 per cent. Windle (157) reports a case in which the oculomotor was divided by a branch of the posterior cerebral. In four instances the basilar was found to bifurcate below the normal position (upper border of pons), in which case the posterior cerebral must inevitably make a more pronounced loop round the IIIrd nerve and consequently endanger the nerve by strangulation, if any force acting in a caudal direction is exerted upon it.

Lautard (86) described very fully the abnormal vessels which compensate for a very small posterior cerebral artery.

### The Posterior Communicating Artery.

This branch of the internal carotid was present in 93 per cent. on both sides, and was absent in 4 per cent. on the right and 3 per cent. on the left. The arteries of the two sides were of equal size in 28 per cent., the right was larger in 35 per cent., and the left in 37 per cent. This is in direct contradiction to the opinion of Box and Eccles (26), who maintain that the right posterior communicating is invariably the larger. Both were unusually large in 3 per cent., and the vessel of either side alone was of extreme size in 1 per cent. Both were minute in 3 per cent., and the left alone was particularly small in 2 per cent.

On both sides in 2 per cent. the posterior communicating was larger than the origin of the posterior cerebral from the basilar, and as a result the latter vessel appeared to be a branch of the internal carotid; this occurred on the right alone in 3 per cent., and the left alone in 3 per cent.

### The Anterior Cerebral Artery.

No marked abnormality of this vessel was noticed. The relative size is of little clinical importance, owing to the practically constant presence of the anterior communicating.

Barkow (10) described a case in which the anterior cerebral arteries fused to form one common trunk in a similar manner to the junction of the vertebrals to form the basilar, a condition found constantly in the lower mammals.

Beaumonoir (15) quotes a case in which the right middle cerebral gave origin to the anterior cerebral artery of both sides. In No. 123 an accessory middle cerebral was found, arising from the left anterior cerebral at the level of the junction with the anterior communicating.

The presence of a middle anterior cerebral, in addition to the right and left, has been noted frequently since the time of Barbieri (8). It was discovered in 6 per cent.

### The Middle Cerebral Artery.

No abnormality in origin or size of this branch of the internal carotid has been noted.

### The Anterior Communicating.

A communication between the two anterior cerebral arteries was found constantly. Barbieri (8), Spitzka (131), and Blackburn (twice in 220) have seen examples of its absence, but it is a very rare condition. A normal single channel was found in 85 per cent., a double communication (partial or complete) in 9 per cent., and in 3 per cent. there was lateral fusion for a short distance without the intervention of any communicating branch. In No. 118 the anterior communicating exhibited a "dimpling," which indicated an attempt at duplication. In one case there was a triple communication, and in another a quadruple or what might be more correctly termed an anastomatic network.

Reference to fig. 5 will make the arrangement of this vessel clearer. Ehrman (56) found the anterior communicating single in 89 per cent., double in 3 per cent., triple in 2 per cent., Y-shaped in 3 per cent., and fusion of the two anterior cerebral arteries in 3 per cent. Mori (99) noted reduplication of the anterior communicating in 14 per cent.

Parsons (107) found this artery absent in many mammals, including Platyrrhine monkeys, the two anterior cerebrals forming a single azygos vessel, which supplies the medial surfaces of both cerebral hemispheres.

Grünbaum and Sherrington (65) found the human type more constant in the chimpanzee and orang, but not invariably present. De Vriese

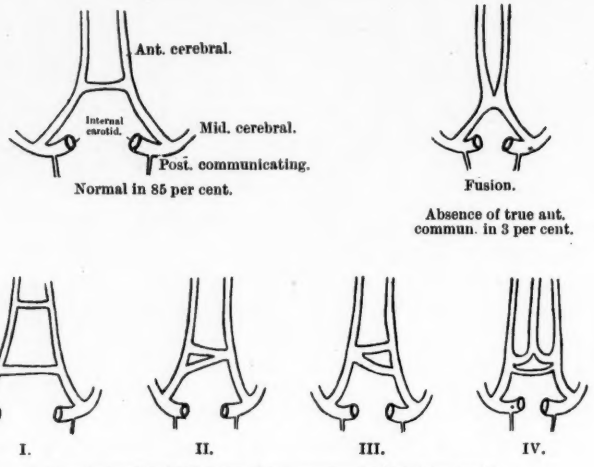



FIG. 5.—Variations of anterior communicating artery.

(47) and Beddard (16, 17, and 18), as in the case of the other cerebral arteries, describe in great detail the morphology and comparative anatomy of this vessel.

### The Internal Carotid.

The only thing in connexion with this artery which has been specially noticed is its close approximation to the optic nerve. This will be considered fully in Part III.

Mitchell and Dercum (98) describe a most interesting case of aneurysm

of an abnormal communication between the terminal parts of the two internal carotid arteries. A similar abnormal communication is mentioned by Incoranto.

TABLE II.

| | Stopford. | Blackburn. | Windle. | Fawcett and Blackford. | De Vriese (Fœtal). | De Vriese (Adult). |
|---|---|---|---|---|---|---|
| | Percentages. | | | | | |
| Number examined | *150* | *220* | *200* | *700* | ... | *25* |
| Complete circle of Willis | 93 | ... | 59 | 96 | ... | 96 |
| I. *Posterior Cerebral.* | | | | | | |
| 1. Size at origin: | | | | | | |
| (*a*) Equal | 32 | ... | ... | ... | ... | ... |
| (*b*) Right larger | 36 | ... | ... | ... | ... | ... |
| (*c*) Left larger | 32 | ... | ... | ... | ... | ... |
| 2. Appeared to arise chiefly from internal carotid: | | | | | | |
| (*a*) Both sides | 2 | 10 | 2 | ... | 30 | ... |
| (*b*) Right side only | 5 | 7 | 5 | 1 | ... | 20 |
| (*c*) Left side only | 3 | 5 | 4 | 1 | ... | 8 |
| II. *Posterior Communicating.* | | | | | | |
| Both present | 93 | ... | 87 | ... | ... | ... |
| 1. Absence: | | | | | | |
| (*a*) Both | 0 | ... | 1 | 4 | ... | 4 |
| (*b*) Right only | 4 | one case | 4 | 2 | ... | ... |
| (*c*) Left only | 3 | ... | 6 | 1 | ... | ... |
| 2. Size: | | | | | | |
| (*a*) Equal | 28 | ... | ... | 89 | 38 | 40 |
| (*b*) Right larger | 35 | ... | ... | 12 | 30 | 32 |
| (*c*) Left larger | 37 | ... | ... | 9 | 32 | 28 |
| Very large: | | | | | | |
| (*a*) Both | 3 | ... | ... | ... | ... | ... |
| (*b*) Right only | 1 | ... | ... | ... | ... | 12 |
| (*c*) Left only | 1 | ... | ... | ... | ... | ... |
| Minute: | | | | | | |
| (*a*) Both | 3 | 2 | 3 | ... | ... | ... |
| (*b*) Right only | 0 | 1 | ... | .. | ... | ... |
| (*c*) Left only | 2 | 3 | ... | ... | ... | ... |
| II. *Anterior Communicating.* | | | | | | |
| Absence | 0 | 1 | 1 | one case | ... | ... |
| 1. Single | 85 | 90 | 79 | 92 | 48 | 80 |
| 2. Double | 9 | 6 | 10 | 7 | 14 | 4 |
| 3. Triple | 1 | ... | one case | one case | ... | ... |
| 4. Quadruple or retiform | 1 | one case | ... | ... | 28 | 12 |
| 5. Fusion of anterior cerebrals | 3 | 3 | 3 | ... | 10 | 4 |
| Presence of arteria media cerebralis anterior | 6 | 1 | 4 | 3 | 12 | 8 |

*The Frequency of Anomalies in Criminals and the Insane.*

In the preface reference has been made to the conclusion that anomalies in the basal arterial trunks occur more frequently in the insane. This conclusion is supported by the results in this series, which is composed of 117 brains from sane individuals and 33 from insane; anomalies were found in 61 per cent. of the former and 79 per cent. of the latter. Considerable emphasis has been placed upon this point by many previous writers, and for comparison the various results will be found tabulated in Table III. Unfortunately, this table loses a good deal of its value, because the various recorders have failed clearly to define what they consider as anomalies, and the greatest reliance can therefore be placed upon the results where the percentages are obtained by the same observer both for the insane and healthy. In this series, absence, irregular origin, reduplication, or a considerable discrepancy in size of any artery has constituted an anomaly.

TABLE III.

| Observer. | Number Examined, etc. | Percentage of Anomalies. |
|---|---|---|
| Blackburn (25). | 220 insane. | 70 |
| Barbieri (8). | 145 idiots. | 15 |
| Frigerio (61). | 37 insane. | 57 |
| Lombroso (89). | 71 criminals. | 37 |
| Mori (99). | 35 insane. | 91 |
| | *35 sane.* | *37* |
| Parnisetti (106). | 65 criminals. | 51 |
| Windle (157). | *200 sane.* | *40* |
| STOPFORD. | *118 sane.* | *61* |
| | 32 insane. | 79 |

## BIBLIOGRAPHY.

(1) ABRAHAMSON, I., "A Case of Thrombosis of the Posterior Inferior Cerebellar Artery," *Journ. Nerv. and Ment. Dis.*, vol. xxxv., 1908 *(New York Neur. Soc.)*.

(2) ADAMKIEWICZ, A., "Die Arterien des verlaengerten Markes," *Denkschr. Akad. Wiss. Wien*, Bd. lvii.

(3) ADAMKIEWICZ, A., "Ueber die mikroskopischen Gefässe des menschlichen Rückenmarkes," *Trans. Inter. Med. Cong. Lond.*, 1891, vol. i.

(4) ALEXANDER, W., "Observations on the Effect of Ligature of the Vertebral Artery in certain Diseases of the Spinal Cord," *Liverpool Med.-Chir. Journ.*, ii., 1882.

(5) ALEZAIS et D'ASTROS, "La circulation artérielle du pédoncle cérébral," *Journ. de l'anat. et de la phys.*, xxviii., 1892.

(6) ANDERSON, R. J., "A New Abnormality in connection with the Vertebral Artery," *Journ. Anat. and Phys.*, xiv., 1879–80.

(7) ANTONIUS, L. M., and CALDANI, F., *Icones anatomicæ*, vol. iii. part iv., 1813.

(8) BARBIERI, A., *Monographia della arteria vertebrale*, Milan, 1867–8.

(9) BARDELEBEN, K. VON, "Nervensystem," in *Handbuch der Anatomie der Menschen*, Jena, 1899.

(10) BARKOW, H. O. L., *Schlagad. der Säugethiere*, 1866, Taf. 43, quoted by Mitchell and Dercum (98).

(11) BASTIAN, C., "Thrombosis of Basilar Artery," *Lancet*, i. 1885 (*Proc. Chir. Soc. London*).

(12) BATTEN, F. E., "Bulbar Palsies," in Allbutt and Rolleston's *System of Medicine*, vol. vii.

(13) BATUJEFF, N., "Eine seltene Arterienanomalie: Ursprung der Basilaris und der Carotis interna," *Anat. Anz.*, iv., 1889.

(14) BEADLES, C. F., "Aneurysms of the larger Cerebral Arteries," *Brain*, vol. xxx., 1907.

(15) BEAUMONOIR, *Les progrès médical*, 1886.

(16) BEDDARD, F. E., "A Contribution to the Knowledge of the Encephalic Arterial System in Sauropsida," *Proc. Zool. Soc. Lond.*, vol. ii., 1905.

(17) BEDDARD, F. E., "A Contribution to the Knowledge of the Arteries of the Brain in the Class Aves," *Proc. Zool. Soc. Lond.*, vol. i., 1905.

(18) BEDDARD, F. E., "On the Arteries at the Base of the Brain in some Mammals," *Proc. Zool. Soc. Lond.*, vol. i., 1904.

(19) BEEVOR, C. E., "On the Distribution of the different Arteries supplying the Human Brain," *Phil. Trans. Roy. Soc.*, ser. B, vol. cc., 1908.

(20) BEEVOR, C. E., "The Cerebral Arterial Supply," *Brain*, vol. xxx., 1907.

(21) BELOGOLOWY, J., "Zur Entwickelung der Kopfnerven der Vögel: ein Beitrag zur Morphologie des Nervensystems der Wirbeltiere," *Bull. Soc. Imp. Moscow*, Abt. iii., unce iv.

(22) BERKLEY, *Mental Diseases*, 1900.

(23) BERNHEIMER, "Ueber die Sehnervenveränderungen bei Hochgradiges der Gehirnarterien," *Arch. für Ophthal.*, Bd. xxxvii. S. 3.

(24) BERRY, R. J. A., and ANDERSON, J. H., "A Case of Non-Union of the Vertebrals, with consequent Abnormal Origin of the Basilar," *Anat. Anz.*, xxxv., 1910.

(25) BLACKBURN, J. N., "Anomalies of Encephalic Arteries among the Insane," *Journ. Comp. Neur. and Psych.*, xvii., 1907.

(26) BOX, C. R., and ECCLES, W. M'A., *Clinical Applied Anatomy*, 1906.

(27) BRAMWELL, BYROM, *Edin. Med. Journ.*, vol. xxxii., 1886–7.

(28) BREMER, J. L., "Aberrant Roots and Branches of the Abducent and Hypoglossal Nerves," *Journ. of Comp. Neur. and Psych.*, xviii., 1908.

(29) BRUCE, A., *Illustrations of the Nerve Tracts in the Mid and Hind Brain*, 1892.

(30) BURY, J. S., and STOPFORD, J. S. B., "On a Case of Occlusion of the Posterior Inferior Cerebellar Artery," *Med. Chron.*, Dec. 1913.

(31) BUZZARD, T., "On Posterior Sclerosis, consecutive to Disease of Blood-vessels," *Brain*, vi., 1883.

(32) CAMPBELL, A. W., "Case of Thrombosis of the Left Inferior Cerebellar Artery, with Cord Lesion," *Liverpool Med.-Chir. Journ.*, vol. xiv., 1894.

(33) Chadwick, C. M., "Embolus of the Basilar Artery," *Brit. Med. Journ.*, i., 1886.

(34) Charpy, A., "Système nerveux," Poirier and Charpy's *Traité d'anatomie*, 2me éd., tome iii.

(35) Coupland, "Thrombosis of Anterior Spinal Artery," *Middlesex Hospital Report*, 1889.

(36) Courtney, J. W., "Case of Thrombosis of the Left Posterior Inferior Cerebellar Artery," *Boston Med. and Surg. Journ.*, vol. clxvi. 1, 1912.

(37) Corin, quoted in Poirier and Charpy's *Traité d'anatomie.*

(38) Cruveilhier, J., *Traité d'anatomie descriptive*, 3me éd., tome ii., 1851.

(39) Cunningham, D. J., "The Significance of Anatomical Variations," *Journ. Anat. and Phys.*, xxxiii., 1899.

(40) Cushing, Harvey, "Strangulation of the Nervi abducentes by Lateral Branches of the Basilar Arteries in Cases of Brain Tumours," *Brain*, vol. xxxiii., 1910–11.

(41) Dana, C. L., "Acute Bulbar Paralysis due to Hæmorrhage and Softening of the Pons and Medulla," *Med. Rec.*, vol. lxiv., 1903.

(42) Dauber, "Zur Lehre von der Poliomyelitis anterior acuta," *Deutsche Zeitschrift für Nervenheilkunde*, Bd. iv.

(43) Davy, J., "On a Peculiarity of Structure occasionally occurring in the Basilar Artery of Man," *Researches Phys. and Anat.*, vol. i. chap. xvi.

(44) Deaver, J. B., *Surg. Anat.*, vol. ii., 1901.

(45) Decker, quoted by Mitchell and Dercum (98).

(46) Delpeck, *Bull. Soc. Anat. de Paris*, vol. xvii., 1843.

(47) De Vriese, Bertha, "Zur Entwicklungsgeschichte der Arteriæ cerebrales anteriores," *Verh. anat. Ges.*, 21. Versamml. Würzburg, 1907.

(48) De Vriese, Bertha, "Sur la signification morphologique des artères cérébrales," *Arch. Biol.*, xxi.

(49) De Vriese, Bertha, "Recherches sur la morphologie de l'artère basilaire," Diss. Inaug. Univ. Gand, 1905.

(50) De Vriese, Bertha, "Sur les artères de la base cerveau," *Anat. Anz.*, xvii.–xx., 1903–6.

(51) Dreschfeld, J., "Acute Disseminated Myelitis," *Brit. Med. Journ.*, i., 1894.

(52) Duffin, "Thrombosis of Vertebral and Basilar Arteries," *Med. Times and Gazette*, ii., 1876.

(53) Duménil, "Atrophie des nerfs hypoglosses, faciaux, spinaux et racines antérieures des nerfs rachidiens," *Gaz. Heldour*, 1869.

(54) Duret, H., "Recherches anatomiques sur la circulation de l'encéphale," *Arch. de Physiol.*, 1874.

(55) Duret, H., "Sur la distribution des artères nouricières du bulbe rachidien," *Arch. de Physiol.*, 1873.

(56) Ehrman, Thèse de Strasbourg, 1858.

(57) Eichhorst, "Erweichungsheit in der Varolsbrüche in Folge von syphilitische Entartung der Arteria basilaris," *Char. Annal.*, Bd. i., 1876.

(58) Elze, C., "Beschreibung eines menschlichen Embryo von zirca 7 mm.," *Anat. Hefte*, 1907.

(59) Fawcett, E., and Blackford, J. V., "The Circle of Willis: an Examination of 700 Specimens," *Journ. Anat. and Phys.*, vol. xl., 1906.

(60) Fleming, R. A., "Notes of a Case of Recurrent Paralysis of the Third Nerve," *Rev. of Neur. and Psych.*, vol. xii., 1911.

(61) Frigerio, quoted by Charpy (34).
(62) Gillis, A. C., "Occlusion of the Posterior Inferior Cerebellar Artery," Report of Cases, *Journ. of Amer. Med. Assoc.*, vol. lxiii., 1914.
(63) Goldscheider, "Ueber Poliomyelitis," *Zeit. für klin. Med.*, Bd. xxii. Hefte 5 und 6.
(64) Gowers, W. R., *Diseases of the Nervous System*, vol. ii., 1893.
(65) Grünbaum, A. S. F., and Sherrington, C. S., "Note on the Arterial Supply of the Brain in Anthropoid Apes," *Brain*, vol. xxv., 1902.
(66) Hale White, W., "Symmetrical Intracranial Aneurysm of the Vertebral Arteries, producing Symptoms resembling Cerebro-spinal Meningitis," *Trans. Path. Soc. Lond.*, vol. xli., 1890.
(67) Hamilton, "On Reflex and Primary Paraplegia," *Brit. and For. Med.-Chir. Rev.*, vol. lxii., 1876.
(68) Handford, H., "Thrombosis of the Vertebral and Basilar Arteries," *Brit. Med. Journ.*, i., 1891 (*Proc. Nat. Med.-Chir. Soc.*).
(69) Harris, W., "A Case of Thrombosis of the Left Posterior Inferior Cerebellar Artery followed by Trigeminal Neuralgia in the Analgesic Facial Area," *Proc. Roy. Soc. Med.*, vol. iii. part ii., 1909–10.
(70) Hayem, "Sur la thrombose par artérite de tronc basilaire comme cause de mort rapide," *Arch. de Phys.*, tome i., 1868.
(71) Head, H., and Gordon, Holmes, "Sensory Disturbance from Cerebral Lesion," *Brain*, vol. xxxiv., 1911–12.
(72) Henle, J., *Handbuch der Gefässlehre des Menschen*, 1868.
(73) Heubner, *Die luetische Erkränkung der Hirnarterien*, Leipzig, 1874.
(74) Howden, R., *Gray's Anatomy, Descriptive and Applied*, 1913.
(75) Hutchinson, *Trans. Clin. Soc.*, vol. viii., 1875.
(76) Hughlings Jackson, J., "Softening of the Brain," *Lancet*, ii., 1875.
(77) Hun, H., "Analgesia, Thermic Anæsthesia, and Ataxia, due to Occlusion of the Left Posterior Inferior Cerebellar Artery," *New York Med. Journ.*, vol. lxv., 1897.
(78) Huret, "Tribut à l'histoire de l'embolie des artère vertébrales," Thèse de Paris, 1873.
(79) Incoranto, A., "Di un' anomalia del polygono arterioso cerebrale coincidente con asimmetria del cranio," *Atti Acad. Med. di Roma*, 1878.
(80) Jeanin, "De l'embolisme cérébral de la sylvienne droite," Thèse de Paris, 1894.
(81) Jones, E., "The Question of the Side affected in Hemiplegia and in Arterial Lesions of the Brain," *Quart. Journ. of Med.*, vol. iii., 1910.
(82) Kadyi, H., "Ueber die Blutgefässe des menschlichen Rückenmarkes," *Anat. Anz.*, i., 1886.
(83) Kingston, *Edin. Med. and Surg. Journ.*, vol. lvii., 1842.
(84) Klippel and Boetean, *Bull. Soc. Anat. de Paris*, vol. lxvii., 1892.
(85) Kolisko, *Ueber die Beziehung der Arteria choroidea anterior zum hintern Schenkel der inneren Kapsel des Gehirnes*, Wien, 1891.
(86) Lautard, M., "Etude sur les anomalies des artères de la base de l'encéphale," Thèse de Paris, 1893.
(87) Lebert, *Bull. Soc. Anat. de Paris*, vol. xi., 1836.
(88) Leidy, J., "Multiple Thrombosis of the Circle of Willis," *Med. News*, vol. lxiv., 1894.
(89) Lombroso, C., quoted by Charpy (34).

(90) Longo, L., "Le anomalie del polygono di Willis dell' uomo studiate comparativomente in alcuni mammiferi ed ucelli," *Anat. Anz.*, xxvii., 1905.

(91) Loomis, *Med. Record*, i., 1872.

(92) Loewenfeld, L., "Zur Lehre von der Miliaraneurysmen des Gehirns," *Wien. med. Wochenschr.*, xxxvii., 1887.

(93) Macalister, A., *A Text-book of Human Anatomy*, 1889.

(94) Mall, F. P., "On the Development of the Blood-vessels of the Brain in the Human Embryo," *Amer. Journ of Anat.*, vol. iv., 1904.

(95) Marie, *Leçons sur les maladies de la moelle*, Paris, 1892.

(96) Maudsley, H., "Embolism of the Basilar Artery, with Meningeal Hæmorrhage from Rupture of Posterior Cerebral," *Trans. Path. Soc. Lond.*, vol. xxxviii., 1887.

(97) Menzies, W. F., "Thrombosis of Inferior Cerebellar Artery," *Brain*, vol. xvi., 1893.

(98) Mitchell, S. W., and Dercum, F. X., "Aneurysm of an Anomalous Artery causing Antero-posterior Division of Optic Nerves and producing Bitemporal Hemianopsia," *Journ. of Nerv. and Ment. Dis.*, vol. xiv., 1889.

(99) Mori, A., "Sulla disposizione delle arterie della base dell' encefalo nei normali e negli alienati," *Mon. Zool. Ital.*, iv.

(100) Moxon, W., "Influence of the Circulation on the Nervous System," *Lancet*, i., 1881.

(101) Neal, H. V., "The Morphology of the Eye Muscle Nerves," *Journ. of Morph.*, vol. xxv., 1914.

(102) Obersteiner, H., *Anleitung beim Studium des Baues der Nervosen Central organe*, Leipzig, 1888.

(103) Ogle, J. W., "Note on a Nerve piercing the Walls of an Artery," *Journ. of Anat. and Phys.*, vol. xxix., 1895.

(104) Ogle, *Med.-Chir. Trans.*, vol. xlii., 1859.

(105) Ormerod, J. A., "Two Cases to illustrate Disease of the Medulla oblongata and Pons varola," *St Bart's Hosp. Reports*, vol. xliii., 1907.

(106) Parnisetti, "Anomalie del poligono arteriose del Willis nei delinquenti in rapporto con alienazioni del cervello e del cuore," *Arch. Psych. Sc. peu ed Antrop.*, xxiii.

(107) Parsons, quoted by Grünbaum and Sherrington (65).

(108) Piersol, G. A., *Human Anatomy*, 1907.

(109) Pope, F. M., "Thrombosis of Vertebral Artery pressing on Glosso-pharyngeal Nerve: Unilateral Loss of Taste at Back of Tongue," *Brit. Med. Journ.*, ii., 1889.

(110) Rauber, *Lehrbuch*, 7th ed., Leipzig, 1906.

(111) Rendall, S. M, "Unusual Abnormality of the Arteries at the Base of the Brain," *Journ. of Anat. and Phys.*, vol. xiii., 1879.

(112) Robinson, A., "The Vascular System," in Cunningham's *Text-book of Anatomy*, 4th ed.

(113) Robinson, G. W., "Occlusion of the Posterior Inferior Cerebellar Artery," *Journ. of Amer. Med. Assoc.*, vol. lxi., 1913.

(114) Romberg, *Diseases of Nervous System*, London, 1853.

(115) Ross, J, "Distribution of the Arteries of the Spinal Cord," *Brain*, vol. iii., 1880.

(116) Ross, J., *A Treatise on the Diseases of the Nervous System*, vol. ii., 1883.

(117) Ruysch, F., *Epistola problematica prima*, Amsterdam, 1724.

(118) SAPPEY, C., "Myologie, Angiologie," *Traité d'anatomie*, tome ii., 1869.
(119) SAVELIEU, quoted in Osler's *Principles and Practice of Medicine*, 7th ed.
(120) SCHIFFER, "Ueber die Bedeutung des Stenson'schen Versuchs," *Centralbl. f. d. med. Wiss.*, 1869.
(121) SENATOR, "Apoplectische bulbar paralyse mit Wechselständiger Empfindungslahmung," *Arch. für Psych.*, Bd. xi., 1881.
(122) SEIMERLUNG, "Zur pathologischen Anatomie der pathologischen Kinderlahmung," *Arch. für Psych.*, Bd. xxvi Heft i.
(123) SMITH, G. ELLIOT, "A Note on Nervous Lesions produced Mechanically by Atheromatous Arteries," *Rev. of Neur. and Psych.*, March 1905.
(124) SMITH, G. ELLIOT, "Note on an Anomalous Anastomosis between the Internal Carotid and Basilar Arteries," *Journ. of Anat. and Phys.*, vol. xliii., 1909.
(125) SHAW, C. G., "Two Cases of Reduplication of the Arteria cerebri posterior," *Journ. of Anat. and Phys.*, vol. xliv., 1910.
(126) SPALTEHOLZ, W., *Hand Atlas of Human Anatomy*, vol. iii.
(127) SPICER, HOLMES, and ORMEROD, *Trans. Ophth. Soc. U.K.*, 1896.
(128) SPILLER, W. G., "Bilateral Oculomotorius Palsy from Softening in each Oculomotorius Nucleus," *Journ. of Nerv. and Ment. Dis.*, vol. xl., 1914.
(129) SPILLER, W. G., "Symptom-complex of a Lesion of the Uppermost Portion of the Anterior Spinal and Adjoining Portion of the Vertebral Arteries," *Journ. of Nerv. and Ment. Dis.*, vol. xxxv., 1908.
(130) SPILLER, W. G., "A Symptom-complex of Occlusion of the Posterior Inferior Cerebellar Artery: Two Cases with Necropsy," *Journ. of Nerv. and Ment. Dis.*, vol. xxxv., 1908.
(131) SPITZKA, quoted by Mitchell and Dercum (98).
(132) STARR, M. A., "Arterial Sclerosis as a Cause of Nervous Disease," *Med. Record*, vol. lxiv., 1903.
(133) STEWART, R. M., "Meningo-vascular Syphilis," *Brit. Med. Journ.*, Feb. 27, 1915 (*Proc. Med.-Psych. Assoc. of Gt. Brit. and Ireland*).
(134) STOPFORD, J. S. B., "A Note on the Significance of certain Anomalies of the Renal and Spermatic Arteries," *Journ. of Anat. and Phys.*, vol. xlviii., 1913.
(135) SWANBERG, H., "The Intervertebral Foramina in Man," *Med. Record*, i., 1915.
(136) TARENETZKY, quoted by Thane (139).
(137) TAYLOR, E. W., "Progressive Vagus-glossopharyngeal Paralysis with Ptosis: a Contribution to the Group of Family Diseases," *Journ. of Nerv. and Ment. Dis.*, March 1915.
(138) TAYLOR, H., "Embolism of Left Vertebral Artery: Paralysis of the Glossopharyngeal Nerve: Death from Starvation," *Brit. Med. Journ.*, ii., 1871.
(139) THANE, G. D., "Angeiology," in *Quain's Anatomy*, vol. ii. part ii., 1892.
(140) THOMAS, H. M., "Symptoms following the Occlusion of the Posterior Inferior Cerebellar Artery," *Journ. of Nerv. and Ment. Dis.*, vol. xxxiv., 1907.
(141) THOMSON, H. C., "A Case of Pontine Thrombosis causing Anæsthesia of the Fifth Nerve and Hemianæsthesia of the same side," *Proc. Roy. Soc. Med.*, vol. iii. part ii., 1909–10.
(142) TOLDT, *Anatomisches Atlas.*
(143) TROUSSEAU, "Lectures on Clinical Medicine," *New Syd. Soc. Lond.*, vol. i., 1868.
(144) TURNER, W., *An Introduction to Human Anatomy*, Edin., 1875.
(145) VALENTI, quoted in Poirier and Charpy's *Traité d'anatomie.*

(146) Valenti et d'Alundo, *Inst. Anat. de Pise*, 1890.

(147) Vicq d'Azyr, M., *Traité d'anatomie et de physiologie*, tome i., Paris, 1786.

(148) Wallenberg, A., "Acute Bulbaraffection," *Arch. für Psych.*, vol. xxxiv., 1901; also *Arch. für Psych.*, vol. xxvii., 1895.

(149) Walsham, W. J., "Arteries, Veins, and Lymphatics," in *A Treatise on Anatomy*, by Morris, 2nd ed.

(150) Weber, L., "Presentation of a Specimen of Occlusion of Basilar Artery," *Med. News*, vol. xlii., 1883 (*New York Neur. Soc.*).

(151) Weber, S. G., "Abnormal Distribution of the Circle of Willis," *Boston Med. and Surg. Journ.*, vol. cvii., 1882.

(152) Weil, "Der Stenson'sche Versuche," Diss. Strass., 1873.

(153) Wilks, S., "Labio-glosso-laryngeal Paralysis," *Guy's Hosp. Reports*, vol. xxx, 1870.

(154) Williamson, R. T., "On the Relation of Spinal Diseases to the Distribution and Lesions of the Blood-vessels of the Spinal Cord," *Med. Chron.*, N.S., ii., 1894–5.

(155) Willis, T., *Opera omnia*.

(156) Wilson, S. A. K., "A Case of Thrombosis of the Left Posterior Inferior Cerebellar Artery," *Proc. Roy. Soc. Med., Neur. Sect.*, vol. ii. part ii., 1908–9.

(157) Windle, B. C. A., "On the Arteries forming the Circle of Willis," *Journ. of Anat. and Phys.*, 1887–88.

(158) Woods, "Segmental Distribution of Spinal Root Nucleus of the Trigeminal Nerve," *Journ. of Nerv. and Ment. Dis.*, vol. xl., 1913.

(159) Bourgery, J. M., *Traité complet de l'anatomie de l'homme*, tome iii., Paris, 1844.

(160) Lewis, B., "Arterial System of the Brain," *Brain*, vol. iii., 1880.

# THE COSTAL MUSCULATURE.

By THOMAS WALMSLEY, M.B.,
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THE rib muscles are differentiated from the other muscles of the thoracic wall by a group of common characters, structural and functional. They represent the thoracic continuation of the abdominal muscular sheets, so that embryologically their derivation is alike; their mode of attachment to the skeleton is uniform, so that they are solely muscles of respiration; their innervation is through the anterior branches of the thoracic nerves; they have a marked tendency to a state of regression. The regression of these rib muscles is evident from their structure. The fleshy contracting part of each fibre is short, and completion is by a long tendinous part, indicating "the adaptation to a feeble amplitude of movement" (Cleland). In certain positions the sarcous part of the fibre may have undergone total regression, and the resulting representative structure is of a fascial nature. This is an emphasis of the fact that wherever fascia are well marked in the body, they represent, in major part, muscles (and their sheaths) which have not entirely lost their function. Possessing the enumerated features and constituting the costal musculature, there are recognised, in addition to the diaphragm, the

M.m. serrati posteriores, superior et inferior.
„ intercostales, externi et interni.
„ levatores costarum.
„ subcostalis et supracostalis.
„ transversus thoracis.

As the abdominal cavity is held to possess, typically, a muscular wall of three strata, homologies have been founded for the costal muscles in an attempt to construct a uniform boundary for the pleuro-peritoneal cavity. But while many of the homologies are definitely established, others are still in dispute For example, some authors consider the subcostalis as part of the "internal oblique sheet" (Cunningham, Le Double); by others it is placed as part of a deeper sheet and in series with the transversus abdominis (Henle, Testut). The following is a contribution towards the establishment of a fuller homology of the costal musculature, and is founded on the demonstration of the compound morphology of the "internal intercostal muscles."[1]

[1] The consideration of the endothoracic fascia will form the subject of a future article.

As described for the adult human subject, the relation of the completely costal members of the anterior thoracic nerves to the "internal intercostal muscles" is that, while posteriorly they are superficially placed, anteriorly they are deep to these muscles, the passage through the muscle being prolonged over some distance (fig. 1). The abdominal intercostal nerves seek a corresponding plane in their "perforation of the intercostalis internus" to run between the internal oblique and the transversalis abdominis muscles. The deep relation of the intercostal nerves in that part of their course deep to the "internal intercostal muscles" has been continuously described as the costal pleura. The branches of the lumbar

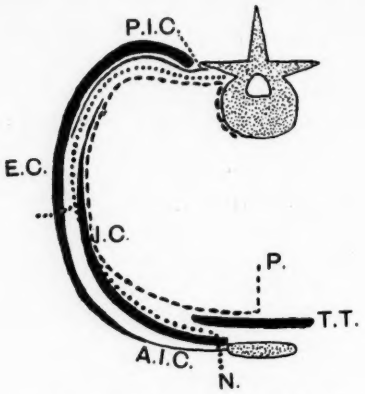


FIG. 1.—Diagrammatic representation of the thoracic wall as presently described.

E.C., external intercostal muscle; I.C., internal intercostal muscle; A.I.C., anterior intercostal membrane; P.I.C., posterior intercostal membrane; T.T., transversalis thoracis muscle; N., intercostal nerve; P., costal pleura.

plexus in series with the intercostal nerves, on the other hand, are not superficial to the internal oblique muscle till their final perforation of this layer, which is described as homologous with the "internal intercostal muscles." The double relationship of the nerve to the muscle, then, is peculiar to the thoracic region, and is such that the muscle may be considered, in relation to the nerve, as of two parts, a posterior portion and an anterior portion, the former being more deeply placed in the thoracic wall. Now, it is known that the origin of the "internal intercostal muscle" from the costal margin differs at different points throughout its length. Souligoux has demonstrated that posteriorly the muscle arises from the inner lip of the costal groove, but anteriorly the origin is from both

the inner and outer lips of that gutter; further, that "the change in the position of the nerve" takes place at the doubling of the muscle. Careful dissection, however, of the "internal intercostal series" has shown that here we are really dealing with two distinct sets of muscles belonging to different tissue planes; that the fusion of these two sets into one as the "internal intercostal muscle" of each space is only an apparent fusion, for throughout their whole contiguous length they are separated by fascial tissue and by the intercostal nerve. The following dissections were carried

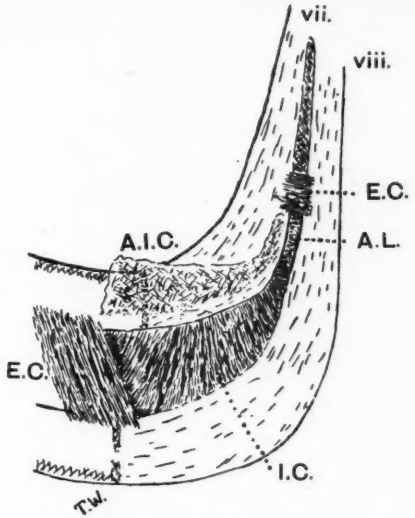


FIG. 2.—To show muscle fibres replacing the anterior intercostal membrane.

A.I.C., in proximity to the interchondral joints; E.C., external intercostal muscle; I.C., internal intercostal muscle; A.L., anterior capsular fibres of the interchondral articulation.

out on ordinary dissecting-room subjects. The sternum and vertebral column were sectioned longitudinally, and each half of the chest wall was treated separately.[1]

1. *Examination of the Superficial Surface of the Chest Wall.*—The external intercostal muscles were first exposed. They commence posteriorly in the region of the tubercles of the ribs and extend forwards to about the costal cartilages. Passing between successive ribs, the origin and the insertion of these muscles are on the lateral surfaces of the opposing

[1] It is proposed to leave for future consideration the relation of the disposition of contractile muscle fibre to function.

borders. In their anterior extension the muscle fibres gradually diminish in amount and the anterior intercostal membrane continues forwards the tissue plane. This membrane reaches the external margin in the upper spaces, but lower down it does not extend beyond the final fusion of the bounding cartilages, and in this region, 6th to 9th interspaces, muscle fibres are occasionally representative, especially in proximity to the interchondral articulations (fig. 2). While the membrane is loosely connected to the capsule of these joints, it does not form the anterior part of the capsule, nor is it in any way specifically interrupted at these positions. In the 10th and 11th interspaces the intercostal muscles extend forwards

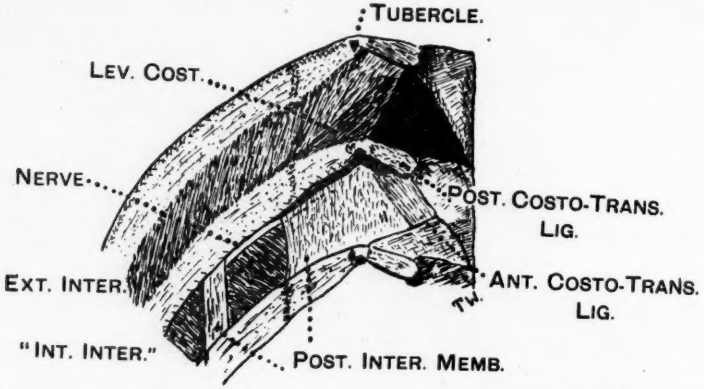


FIG. 3.—In the lower space the external sheet of the thoracic musculature has been reflected. The muscle called the "internal intercostal" will be noted as deep to the posterior intercostal membrane. (In the B.N.A. terminology the post. costo-trans. lig. is the lig. tuberculi costæ, and the ant. costo-trans. lig. is the anterior part of the costo-transverse lig.)

deep to the posterior border of the corresponding digitation of the external oblique muscle of the abdominal wall, and a membrane of delicate structure continues the muscle anteriorly between the external and internal oblique muscles, and finally fuses with the aponeurosis of the latter muscle. Posteriorly the levatores costarum (long. et brev.) are in series with the external intercostals. The supracostalis, extending from the first rib over two or three spaces, may or may not be present, but is also a derivative of this sheet. This layer of the costal musculature, then, comprising the levatores costarum, the external intercostals, and the anterior intercostal membranes and the supracostalis, forms a complete external sheet from the vertebral column to the sternum, and is homologous with the external oblique muscle of the abdominal wall.

2. *Reflection of the External Sheet in the Whole of its Extent and Definition of the Anterior Parts of the Costo-transverse Ligaments.*—Nowhere are the intercostal nerves yet exposed. At the vertebral extremity of each space the posterior intercostal membrane is shown as a strong fascial layer which, towards the median plane, fuses with the anterior part of the costo-transverse ligament (fig. 3). Passing forwards in each space, this membrane becomes continuous with a layer of muscle tissue which, like the membrane, has its origin from the lateral lip of the costal groove. This muscle sheet, commencing as a thin layer about the mid length of each space, gradually increases in volume and, retaining throughout the original superficial relationship to the intercostal nerve, reaches, in the upper spaces, the sternal margin (fig. 4). In the lower intercostal spaces the anterior ex-

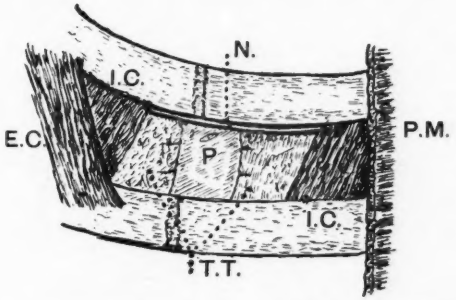


FIG. 4.—Dissection of the sternal end of the 3rd intercostal space.
N., intercostal nerve; E.C., external intercostal muscle; T.T., intra-costal membrane; P., pleura; P.M., pectoralis major.

tension of the muscular tissue is interrupted at the interchondral articulations, and the anterior fibres of the capsules of those joints have the same direction as the fibres of the muscle (fig. 2). In the 10th and 11th spaces the internal oblique muscle of the abdominal wall is directly continuous with the anterior portions of these intercostal muscles. The second layer, then, of the thoracic wall musculature is composed of the posterior intercostal membranes and the anterior parts of the "intercostales interni" muscles, and it arises throughout its whole length from the lateral lip of the subcostal groove and is entirely superficial to the intercostal nerves.

3. *Examination of the Deep Surface of the Chest Wall.*—The costal pleura and the extra-pleural fat were removed; it was noted that the fat is accumulated on the rib surfaces and is absent over the muscular tissue. The transversus thoracis muscle is seen to conceal the terminal portions of the upper intercostal nerves. When traced laterally this muscle becomes

continuous with a fascial layer of varying density, *through which* the intercostal nerves are visible (fig. 5). In all cases, however, the fascia is strong enough to allow of reflection, and will be found attached to the inner surfaces of contiguous ribs. At its commencement the fascia is striated in series with the parent muscle, and in a few cases a similar disposition of actual fleshy fibres will be found (Camper, Tarin). Continued laterally, the fascial fibres give place to muscular fibres, which also have their attachments on the medial surfaces of the bounding ribs. Commencing about mid-way in each space, this muscle sheet increases in volume and extends backwards deep to the posterior intercostal membrane, where it forms the subcostalis by passing over one or more ribs, and is continued as fascia or as muscle (Macalister) from about the angles of the ribs to the vertebral

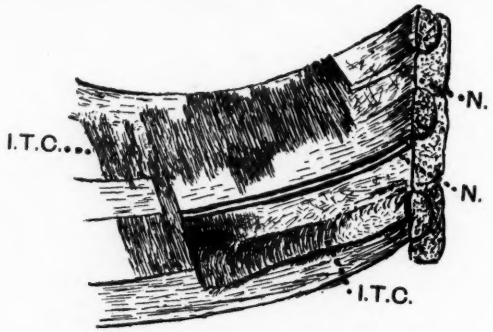


FIG. 5.—In the lower space the intracostal muscle and the fascia extending to the vertebral column has been reflected, thus exposing the intercostal nerve lying on the internal intercostal muscle and the posterior intercostal membrane.

column. In the 10th and 11th spaces it is possible to trace the transversalis abdominis as a fascial layer, in contact with the pleura, posteriorly to become muscular tissue disposed as in the upper spaces. Here we are dealing with the third layer of the thoracic musculature, throughout its whole length deep to the intercostal nerves. It comprises the transversus thoracis muscle, a layer of fascia in loose contact with the pleura derived from that muscle and from the transversus abdominis, the posterior parts of the "internal intercostal" muscles, and the subcostal muscle.

The "internal intercostal" muscle of each space, then, consists of two parts, morphologically distinct. The anterior portion is the more superficial, belongs to the internal oblique sheet, and is properly termed the internal intercostal muscle. It arises from the lateral lip of the costal groove, and is inserted into the upper border of the rib below, the striation being down-

wards and backwards. It is confined to the anterior two-thirds of each intercostal space. The posterior portion of the double muscle is in the plane of the transversalis sheet, and is hereinafter termed the intracostalis. It arises from the medial lip of the costal groove, and is inserted into the upper border and the medial surface of the succeeding rib, the striation again being downwards and backwards. The intracostal muscle is present in about the middle two-fourths of each space, and where it is contiguous with the internal intercostal muscle apposition has been described as fusion.

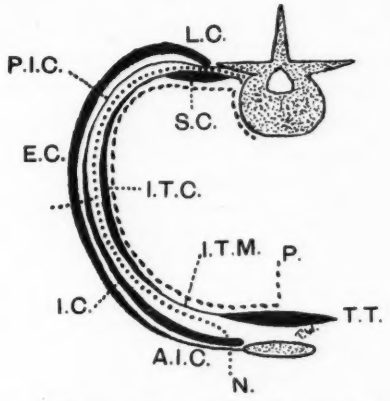


FIG. 6.—Diagram of the thoracic wall as reconstructed.

L.C., levator costæ; I.T.C., intracostal muscle; S.C., subcostalis; I.T.M., intracostal membrane; N., nerve.

The thoracic wall musculature, therefore, consists of three distinct layers (fig. 6):

A. External layer.—Levatores costarum, intercostales externi and the anterior intercostal membranes, supracostalis, and the serrati.

B. Middle layer.—Intercostales interni and the posterior intercostal membranes.

C. Internal layer.—Transversus thoracis, intracostalis, and the intracostal membrane, and the subcostalis.

These layers are each homologous with the corresponding layer of the abdominal wall, and the intercostal nerves preserve the typical relationship to the muscular strata.

# THE TRANSITION OF THE CILIATED EPITHELIUM OF THE NOSE INTO THE SQUAMOUS EPITHELIUM OF THE PHARYNX.

By W. Sohier Bryant, A.M., M.D.

In an effort to determine the boundary lines between the squamous epithelium and the ciliated epithelium of the rhinopharynx, an examination was made of the rhinopharynges in the domestic rabbit, eight individuals;

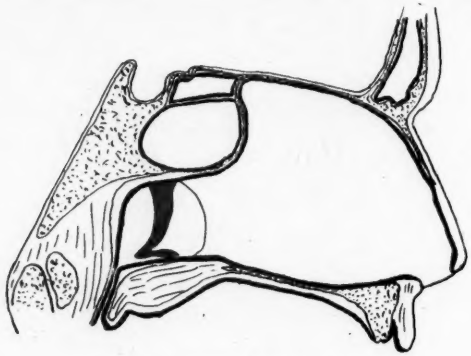

Fig. 1.—Human pharynx, adult.

The intermediate epithelial band (represented by blue area) extends forward on the back wall to near the septum and backward nearly to the angle of the rhinopharynx. The band passes over the Eustachian tube and inclines backward at the union of the soft palate with the lateral wall. The band then inclines forward to a point near the basal septum of the floor of the rhinopharynx.

in the guinea-pig, three individuals; in the domestic cat, four individuals; in the macacus and cebus monkeys, one each; and in man, twelve individuals—adults, children, infants, and fœtus. The search for these boundary lines demonstrated the presence of a third variety of epithelium (mentioned by von Ebner), which, in the character of its cells, is intermediate between the squamous cells and the ciliated columnar cells. This epithelium, which occupies the transitional zone between the epithelium of the oropharynx and that of the nasal fossæ, is composed of cuboid cells with imperfect cilia or no cilia at all.

In all the specimens examined, the squamous epithelium extends as

far forward as the fossæ of Rosenmüller. The intermediate zone of the epithelium occupies the region of the orifice of the Eustachian tubes, while

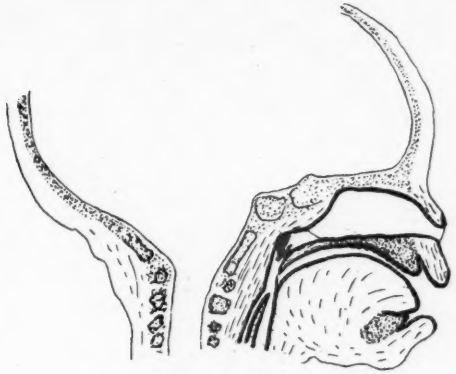

FIG. 2.—Human fœtus at term.
The band of intermediate epithelium extends a little further back than in the adult.

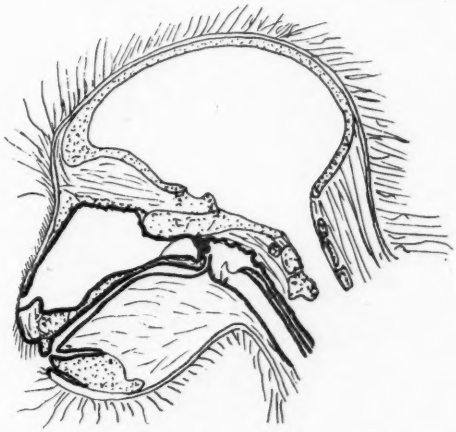

FIG. 3.—Macacus monkey.
The band of intermediate epithelium lies behind the Eustachian orifice.

the ciliated columnar epithelium extends a variable distance backward, approaching the Eustachian tubes.

The intermediate zone of the epithelium lies in a wavy ring around the

naso-rhinopharynx. It bends forward on the anterior and the posterior walls, and backward on the lateral walls at the attachment of the posterior

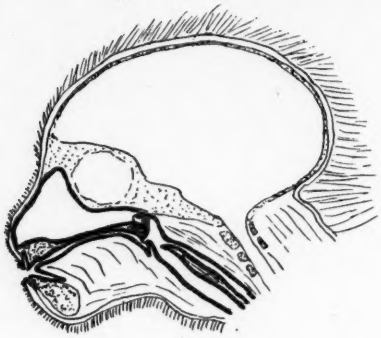

FIG. 4.—Cebus monkey.
The band of intermediate epithelium lies behind the Eustachian orifice.

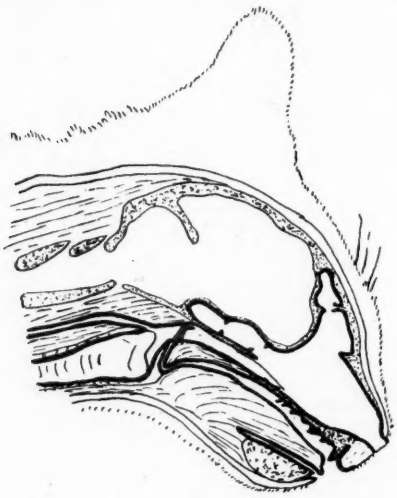

FIG. 5.—Domestic cat.
The band of intermediate epithelium lies behind the Eustachian orifice.

faucial pillars. The zone includes interdigitations and islands of the neighbouring varieties of epithelium.

The boundaries of the intermediate zone of epithelium vary in position,

as stated by von Ebner; but the boundaries of this intermediate zone, I find, contrary to von Ebner, are constant, inasmuch as they vary

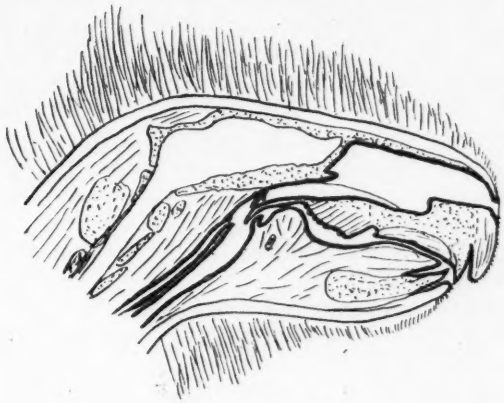

FIG. 6.—Guinea-pig.
The band of intermediate epithelium lies across the ustachian orifice.

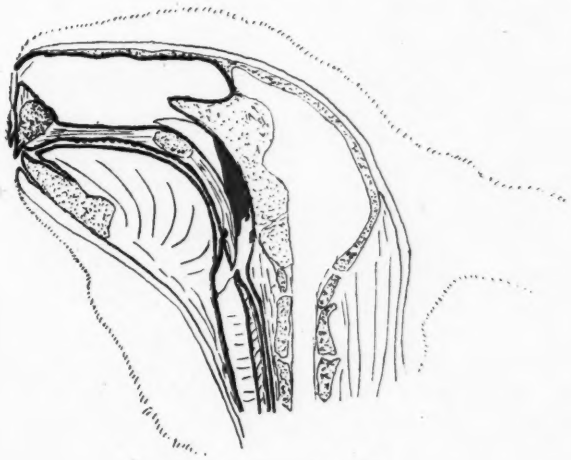

FIG. 7.—Domestic rabbit.
The band of intermediate epithelium is wide, and lies in front of the Eustachian orifice.

between fixed limits. In the various species the variations have specific limitations.

1. In the rabbit the anterior border of the transition extends far in front of the Eustachian orifice. The posterior border reaches this orifice.

2. In the guinea-pig the intermediate zone ends anteriorly a short distance in front of the Eustachian orifice. This zone ends posteriorly a short distance behind the Eustachian orifice.

3. In the cat the anterior border of the intermediate zone crosses the Eustachian orifice, while the posterior border is a short distance behind this orifice.

4. In the cebus and macacus monkey and in man the position of the anterior and posterior boundaries of the intermediate epithelial zone resembled very closely the type found in the cat.

The intermediate zone is seen to extend furthest forward in the rabbit and furthest back in man.

The figures presented here are diagrammatic projectoscopic outlines of vertical antero-posterior sections of the head with the nasal septum preserved. The shaded lines represent the cut edges of the mucous membrane. The blue area represents the band of intermediate epithelium between the ciliated columnar epithelium and the squamous epithelium.

These observations were made in the Pathological Laboratory of the Manhattan State Hospital through the courtesy of Dr William Mabon, superintendent, and Dr Clarence O. Cheney, pathologist.

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REFERENCE.

VON EBNER, "Schlundkopf-Pharynx," Koelliker's *Handbuch der Gewebelehre des Menschen*, 9th edition, Leipsic, 1902, vol. iii. p. 127.

## HEREDITARY ABNORMAL SEGMENTATION OF THE INDEX AND MIDDLE FINGERS.

By H. DRINKWATER, M.D., M.R.C.S. (Eng.), F.L.S.

THE hands referred to in this communication show several peculiarities, the most striking being a marked reduction in the length of the index and middle fingers, so that the ring finger projects far beyond the others

FIG. 1.

(*see* figs. 1 and 2). Both hands are similarly affected. This condition is known to have been hereditary through at least four generations, but it has not been possible to trace it further back. The pedigree is shown in fig. 3.

The two fingers referred to remind one of the digits in brachydactyly, but there all the fingers are affected.[1]

[1] "An Account of a Brachydactylous Family," by H. Drinkwater, *Proc Roy. Soc. Edin.*, vol. xxviii., part i. (1907), and "A Second Brachydactylous Family," by the same author, *Journ. of Genetics*, April 1915.

The radiographs show certain features which do not seem to have been recorded previously. Fig. 4 is the radiograph of the hands of a girl aged nineteen (No. 9 in the chart).

Fig. 2.

It shows: (1) An abortive condition of the middle phalanx in each finger, which is seen to be reduced to about one-third its normal length.

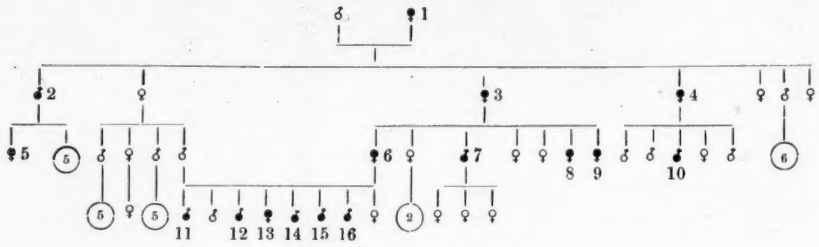



Fig. 3.—The family pedigree.

♂ = normal male. ♀ = normal female.
♂ = abnormal ,, ♀ = abnormal ,,

This is the one essential feature of brachydactyly. The hands are therefore brachydactylous.

(2) The proximal phalanx in the ring finger is abnormally long.

(3) The base of the proximal phalanx of the index finger is very oblique (normally it is at right angles to the length of the bone). (Fig. 13; No. 6 in chart.)

(4) The proximal phalanx of the middle finger appears to be divided into two in the middle of its length. This was the first radiograph which I procured, and if certain others had not been forthcoming it would have been impossible to account for the very striking peculiarities just enumerated—namely, the oblique base of the proximal phalanx in the

Fig. 4.

index finger, and the two bones in place of the normal one (proximal phalanx) in the middle finger.

### The Proximal Phalanx of the Middle Finger.

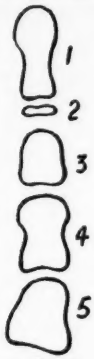
In No. 9 (fig. 4) this appears to be divided in the middle transversely. A precisely similar condition is present in No. 7 (fig. 5), but in No. 11 (fig. 6) the division is much nearer the base, whilst in No. 15 it is nearer the distal end of the bone.

In the younger individuals the bones are not fully ossified, and the epiphyses are not yet ankylosed. They help to elucidate the nature of the abnormality.

FIG. 5.

FIG. 6.

In No. 12, a boy aged thirteen (figs. 1, 7, and 8), the middle finger shows the following bones, counting from the distal extremity :—




1 The shaft of the distal phalanx.

2 Its epiphysis.

3 The abortive middle phalanx without any epiphysis.

4 A longer bone than 3, with rounded head.

5 A bone of approximately the same length as 4. Next to this is seen the head (epiphysis) of the metacarpal bone.

FIG. 7.

FIG. 8.

A normal hand shows a single bone in place of 4 and 5, of about their combined length ; with a thin plate-like bone (the epiphysis) at the base, (like 2) before ankylosis has occurred.

The conclusion is perhaps justifiable that the normal phalanx has become divided into two approximately equal portions. This also is the conclusion one would come to from an examination of the hand of No. 9. It is, however, practically certain that this would be an erroneous interpretation.

What then is the nature (homology) of these two bones marked 4 and 5? Is 5 the lower half of the shaft, or is it an overgrown epiphysis, or something else? I will endeavour to answer these questions later on.

The axis of 5 is not in line with the axis of 4, as one would expect if they both belonged to the shaft.

## The Proximal Phalanx of the Index Finger.

In every abnormal individual in this family the radiographs show this bone to have an oblique base.

In fig. 11 (boy aged nine years) what appears to be the epiphysis is a triangular bone, and it is obvious that after ankylosis has occurred the base will be oblique as in all adult abnormal members of the family. But *is* it the epiphysis?

Let us now look again at No. 12 (figs. 8 and 9), and trace the bones in the index, as was done in the middle finger. It shows:—

1 The shaft of the terminal phalanx.
2 Its epiphysis.
3 The abortive middle phalanx.
4 A thin plate which is to form the "head" of the proximal phalanx.
5 The shaft of the proximal phalanx.
6 Its epiphysis.
7 A triangular bone interposed between 6 and the head (epiphysis) of the metacarpal bone.

Fig. 9.

This triangular bone is so placed that the finger is tilted away from the thumb, and when ankylosis occurs the base of the proximal phalanx will have an oblique direction. There is no doubt that the obliquity of the base seen in this phalanx in the adult hands is due to the presence of a similar

triangular bone which has become ankylosed with the shaft of the proximal phalanx and forms its basal position. In those cases where this triangular bone is the only one present on the proximal side of the shaft, it would appear that the epiphysis is absent.

What is this triangular bone? The only interpretation which seems warranted by a study of this series of radiographs is that it is an extra bone—one which is not present in the normal hand.

It is probably due to an abnormal segmentation of the row of mesoblastic cells which form the primitive basis for the osseous skeleton of the digit. It *may*, however, be due to an intrusion of surrounding cells, and this might explain the triangular shape, which one would not expect to see

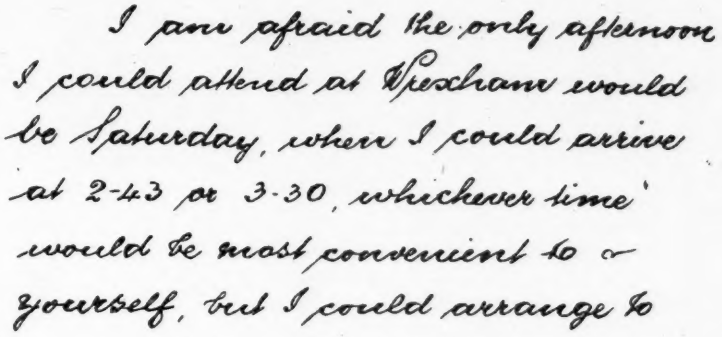

I am afraid the only afternoon
I could attend at Wrexham would
be Saturday, when I could arrive
at 2-43 or 3-30, whichever time
would be most convenient to
yourself, but I could arrange to

FIG. 10.—Specimen of the handwriting of No. 7 (fig. 5).

resulting from a transverse segmentation. Though from the data to hand it is impossible to speak dogmatically, an abnormal segmentation seems the most likely explanation.

We can perhaps now speak more positively about the peculiarity seen in the middle finger. I conclude that the bone marked 5 in figs. 7 and 8 is homologous with the triangular bone in the index finger, for the following reasons:—

1. It is not, as one would expect it to be, in line with 4, which is undoubtedly the shaft of the proximal phalanx.

2. In several cases it is seen to have the same triangular "cocked hat" shape (fig. 11).

3. In fig. 6 (No. 11) one can see the dark line about $\frac{1}{8}$ inch from the base of the phalanx indicating the union of the epiphysis with the shaft—*i.e.* the basal attached portion is the epiphysis, so that the separate bone below this is an extra piece.

FIG. 11.

FIG. 12.

FIG. 13.

FIG. 14.

4. In several adults, when ossification is complete there is a distinct thickening in the place of union of this extra portion with the true phalanx (fig. 12). Thus there seems to be an extra bone in the index and middle fingers.

The feet show ordinary brachydactyly.

This family is an illustration of Mendelian inheritance. The condition is due to some mendelising factor. It is not transmitted by the normal members of the family.

There are 36 descendants of the abnormal members of the family, and of these 15 show the abnormality. Most of the males are labourers; one (No. 7, fig. 5) is a clerk, and writes an excellent script (fig. 10).

No. 6 married a normal cousin.

One radiograph (fig. 4) was taken by Dr J. Elliott of Chester; all the others were taken by Dr Geoffrey Williams of Wrexham. To both of these gentlemen I wish to express my indebtedness and gratitude for their indispensable share in the work.

# THE MEASUREMENT OF DIAPHYSIAL GROWTH IN PROXIMAL AND DISTAL DIRECTIONS.

By KENELM H. DIGBY, M.B., F.R.C.S., *Professor of Anatomy, University of Hong-Kong.*

THE nutrient foramen of the shaft of a long bone transmits the vessels which provide blood for the ossifying cartilage during growth, for the resulting bone, and later for the medulla. The original artery which accompanies the initial invasion of the primitive cartilaginous rod by osteoclasts and osteoblasts enlarges and persists as the nutrient artery. Bone is deposited round the vessel, thus forming a permanent track which traverses the compact tissue in a most oblique direction for from one-half to two inches and more, according to the particular bone. The nutrient foramen in the adult is only the external opening of the nutrient canal.

It follows from its manner of formation that the nutrient canal always points towards the oldest part of the shaft of a long bone. It is more accurate to say that the canal points towards *the site which the oldest part of the bone would occupy were it not that the osseous tissue first formed is subsequently absorbed in providing the medullary cavity.* Indeed, but for this absorption the bottom of the canal would be formed by the very earliest deposit of bone.

If the various long bones of the body are sawn longitudinally so that the nutrient canal lies in the plane of division, the initial point of ossification may be easily determined, for it corresponds to that point in the centre of the medullary cavity which is reached by an imaginary prolongation of the nutrient canal. The site of initial ossification having been determined, it becomes easy to measure the precise lengths of bone which are formed from the two growing ends of the diaphysis.

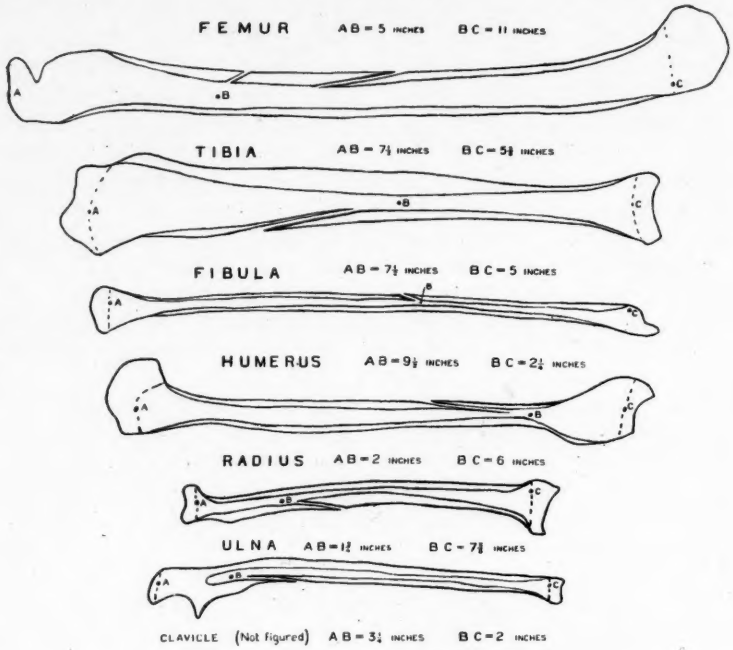
The result of such an examination of the principal long bones of the human body is as follows:—

| Name of Bone. | Formed from Proximal End of Diaphysis. | | Formed from Distal End of Diaphysis. | |
|---|---|---|---|---|
| | Length in Inches. | Proportion of Whole Diaphysis. | Length in Inches. | Proportion of Whole Diaphysis. |
| | | per cent. | | per cent. |
| Femur | 5 | 31 | 11 | 69 |
| Tibia | 7½ | 57 | 5⅝ | 43 |
| Fibula | 7½ | 60 | 5 | 40 |
| Clavicle | 3¾ | 62 | 2 | 38 |
| Humerus | 9½ | 81 | 2¼ | 19 |
| Radius | 2 | 25 | 6 | 75 |
| Ulna | 1⅜ | 19 | 7⅝ | 81 |

## Notes.

1. These bones were taken from different bodies. A thorough examination of a large series of each bone is desirable to provide reliable averages.

2. It is generally assumed that the obliquity of the nutrient canal results from the fact that whilst a bone grows in length chiefly from one end, the vessel, from which the nutrient artery springs, grows equally throughout its




Tracings of longitudinal bone sections.

A, upper end of diaphysis; B, initial site of ossification; C, lower end of diaphysis.

length. Relative changes in the position of the proximal end of the artery, however, might also be a factor in determining the degree of obliquity. But, anyway, the canal leads inwards to the initial site of ossification.

That this is so is confirmed by the presence of the nutrient foramina in very young bones—before the fourth month of fœtal life; and also in the case of the adult femur where, when two foramina are present (as not infrequently happens), the nutrient canals have different obliquities, so that when prolonged they converge on almost the same point in the medullary cavity.

# THE GENITALIA OF GALEOPITHECUS.

By FREDERIC WOOD JONES, D.Sc., *Professor of Anatomy, University of London, London School of Medicine for Women.*

THE species I have examined is that which inhabits the Malayan Islands and is generally known as *Galeopithecus volans* (for nomenclature and specific characters see Waterhouse, G. R. (1) and Gray, J. E. (2)). It is that commonly known by the native name "Colugo" in the Straits Settlements (for further details see Dennys, N. B. (3)), and, according to Charles Hose (4), as "Kubang plandok" in the Baram district of Borneo. This Bornean term is a curious one, since "kubang" is also the native name for the flying squirrels of the genus *Pteromys* (although in strict Malay it signifies a wallow pool), and "plandok" is the native name for the mouse-deer of the genus *Tragulus*. It would seem that even to the Malay the animal is somewhat of a zoological puzzle.

## MATERIAL.

I have had the opportunity of examining one adult male, one adult female, and one young female. These were all spirit specimens in an excellent state of preservation; they were collected by Dr Charles Hose in the Baram River district of Borneo (see 4), and were placed at my disposal by the kindness of Professor G. Elliot Smith. The genitalia of the male after examination, and subsequent exhibition at the Arris and Gale lectures in 1914, were preserved as a specimen, since added to the collection of the Museum of the Royal College of Surgeons.

## REPRODUCTION.

Concerning the breeding habits but little seems to be recorded. Wallace has noted some interesting points regarding the young (5): "It is said to have a single young one at a time, and my own observation confirms this statement, for I once shot a female, with a very small blind and naked little creature clinging closely to its breast, which was quite bare and much wrinkled, reminding me of the young of Marsupials, to which it seemed to form a transition." Dr Cantor has added some more details in his account of Malayan animals (6); for he says: "Of a number of females with young, none had more than one offspring, which was carried

wrapped in the wide mantle-like membrane." It is possible that Wallace's idea that there was a reminiscence of marsupial conditions in this single offspring may not be so fanciful as it, at first sight, appears to be. It seems certain that the young is born in a very immature condition, and that at any rate a functional imitation of the marsupial physiology is present, the membrane recess forming a false marsupium for the reception of the premature young.

## Reproductive System.

Most features of the reproductive system have been previously described in detail, and there is no novelty nor originality in the record I have made of the condition present in these animals; but I have undertaken this re-examination as part of an ordered study of the genitalia, not only of *Galeopithecus* but of its probable kindred.

By far the best account of the anatomy of *Galeopithecus* is to be found in the well-known monograph of Wilhelm Leche (7). It is true that the genitalia do not here receive quite so much detailed attention as is devoted to some of the other systems; nevertheless there is but little to add to this account, which was written thirty years ago. The work of Chapman (8) carries the description of the genitalia but little beyond the results arrived at by Leche. Chapman examined one male spirit specimen from the Baram River district of Borneo, and subsequently the viscera of another male from Sumatra; no female was dissected or examined. Although for most details the work of Leche is quoted by Chapman, his conclusions are in some respects independent, and will be referred to later. Leche has fully described the internal genitalia of the female, and has figured the condition of the Müllerian ducts in two specimens he examined.

The adult female which I have dissected differed in no way from the description given by Leche, save in those details which obviously depend upon the fact that in this specimen there has been a recent pregnancy. The two uteri are entirely separate, and each opens by a separate orifice upon an elevation which projects into the vaginal lumen after the manner of the human portio vaginalis of the cervix (see fig. 1). The walls of the uteri are thick in my specimen, and the mucous membrane is spongy; in the larger left uterus was some débris, partly adherent to the uterine wall, which probably marked the placental site. The uteri are roughly pyriform, tapering towards the vaginal opening, and they are situated one upon each side of the rectum behind the bladder. The left uterus in my specimen measures 28 mm. in its long axis, and it is double the length and considerably more than double the size of its fellow. The

Falloppian tubes are narrow and tortuous, winding round the medial and cephalic aspects of the small elongated ovary. Upon the right (non-pregnant) side the Falloppian tube joins the apex of the uterus; but upon the left (pregnant) side the enlargement of the uterus has taken place to some extent above the insertion of the tube, and the tube therefore

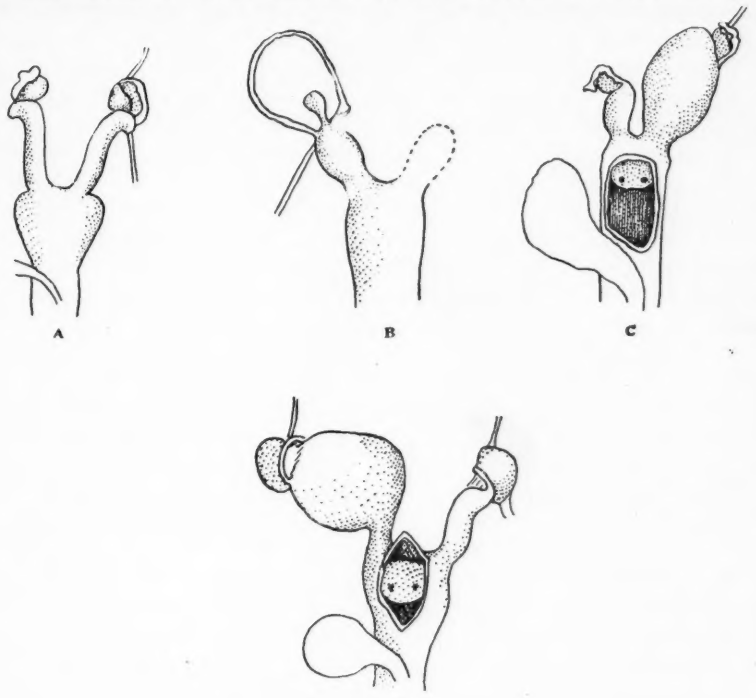



FIG. 1.—Internal genitalia of the female.

A, new-born female (Zool. Mus., Leiden), from Leche, plate v. fig. 41. B, adult female, from Leche, plate v. fig. 40. C, adult female, probably recently pregnant. D, pregnant female bat (*Cynonycteris amplexicaudata*), from Robin, plate vii. fig. 47.

enters the uterine cavity some distance below its apex. The vagina is a wide cavity; its walls are extremely thin, and its lining membrane is glistening. I find no folds upon the vaginal wall such as are described by Leche, and I imagine it is possible that they disappear after pregnancy. The urethra opens just within the vulva, and there is therefore practically no urogenital sinus proper in the female.

Leche has described and figured the external genitalia of the adult

female, and Gervais has figured the condition present in the young (see 9). Leche's figure does not appear to me to be satisfactory in all respects, and I have ventured to give a new illustration of the details of the external genitalia as they are present in the adult specimen I have had the opportunity of dissecting (see fig. 3). The figure given by Gervais, however, represents exactly the condition present in my young example, and I have only thought it worth while to furnish an illustration of this specimen since it shows some of the debated points in the anatomy of the young *Galeopithecus* to which, so far as I am aware, Professor W. K. Parker was the first to call attention (see fig. 2).

In the young female the genital orifice is almost slit-like, the long axis of the opening being in the long axis of the body. The lateral margins of this slit form two slight folds, meeting in front and diverging slightly behind where the orifice becomes more widely opened. The cephalic meeting of these folds marks the site of the tip of the genital tubercle, and they are therefore to be regarded as the inner genital folds or labia minora. It would be difficult, or impossible, from this specimen, or from any of the material that I have examined, to determine exactly what was the anatomical representative of the outer genital folds. A very much earlier stage of development is needed for following the fate of these structures. Fortunately, the very point in which *Galeopithecus* shows a somewhat anomalous form of development is found very exactly paralleled in other animals of which it is possible to examine a series of younger stages. To this point I will return, and, passing over the evidence for the present, will homologise as outer genital folds those curious skin folds which, running from the sides of the genital orifice, surround the anus and, leaving it at the bottom of a deep pocket, meet behind upon the base of the tail.

In the adult several changes have taken place. The genital tubercle and its associated labia minora have enlarged considerably, and with this enlargement there has proceeded a most marked flattening of the parts in an antero-posterior direction. The clitoris and its folds become almost leaf-like, and they constitute one of the striking features of the genitalia of *Galeopithecus*, for they shut down over the genital orifice as a sort of flap which closes the rather capacious vulva. In the illustration of the parts I have figured this flap as raised up from the vulval orifice. It is the presence of this structure which makes the outlet of the adult female genitalia appear to be more or less transverse to the long axis of the body. The labia minora are not confined to the free portion of the clitoris which forms the flap, but they pass backwards as rather inconspicuous folds about half way along the vulval outlet. It is worthy of note that the clitoris, although it is broadened and flattened as I have described, is perforate; in

FIG. 2.—Young female (natural size), showing external genitalia and suprapubic skin folds.

my specimen a probe could be passed into the canal for a distance of some 7 mm., but this canal does not communicate with the urinary tract, and ends blindly. I do not follow Leche in regarding this pocket merely as a recess of the preputium clitoridis, although the preputium provides an ample hood for the clitoris, nor do I find in my specimen an anatomical condition of the clitoris exactly similar to that which he describes. Although in

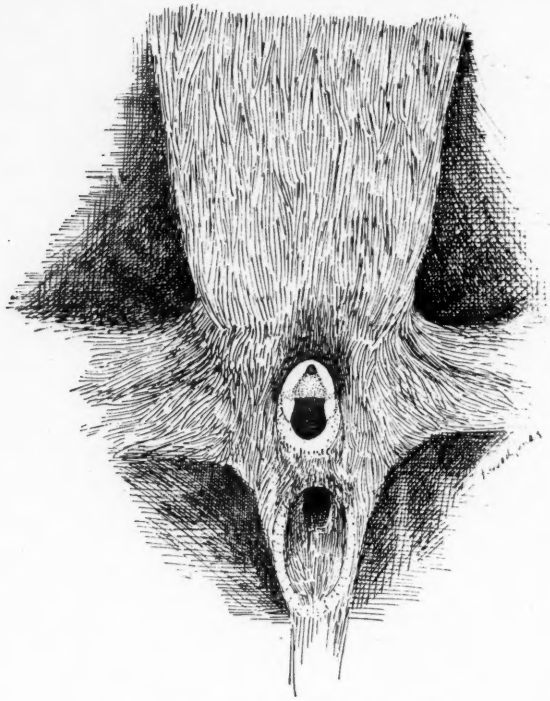


FIG. 3.—External genitalia, adult female.

*Galeopithecus* this blindly-ending canal of the clitoris is conspicuous, the animal is not peculiar in its possession, for it represents a common embryonic and a not uncommon adult phase in certain animals. The urethra opens at a patulous orifice just within the vulval cleft upon the anterior wall of the terminal portion of the vagina.

The internal genitalia of the male possess no very noteworthy features; Cowper's glands are present, and are, as Leche has noted, in every way similar to those seen in the Chiroptera and the Insectivora generally.

The male external genitalia are, however, very peculiar, and I have figured the condition present in my specimen, since Leche gives no figure of the undissected parts (see fig. 4). The testes are external, and carried in a scrotum suspended from the region of the root of the penis in advance of the anal opening. From the scrotal areas the curious folds which encircle the capacious anal pocket are continuous. This anal pocket of the male is deep and wide; it constitutes a very curious skin-lined pouch, the anus being situated deeply within the pouch and completely hidden from

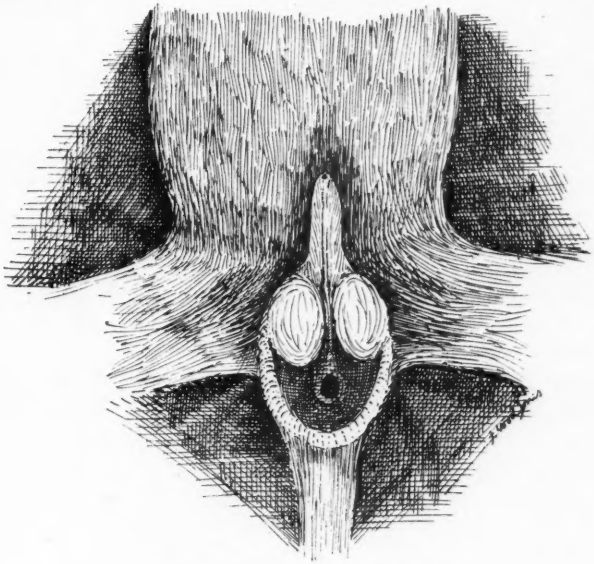


Fig. 4.—External genitalia, adult male.

view in the natural condition of the parts. What may be the functional purpose of this pouch I do not know; it is rather better developed in my male specimen than in the female, although it is a very striking feature in both sexes. It is lined by short fine fur, is evidently capable of contraction and expansion, and is quite unsoiled by intestinal contents in my specimens. The hinder parts of the scrotal areas invade the anterior portions of the pouch.

The penis is pendulous, and is marked by a median raphé which passes back between the two halves of the scrotum and, entering the pouch, disappears in the neighbourhood of the anterior margin of the anus. The

glans of the penis is not simple, but is best described as being trilobed; the median portion, perforated by the urethra, forming the bulk of the glans; the lateral lobes constituting spur-like processes of the main portion. The penis is provided with a suspensory ligament, and its muscles—the ischio-cavernosus, pubo-cavernosus, and bulbo-cavernosus—are well developed, and require no special description; there is a conspicuous m. retractor preputialis which obtains a bony origin from the public rami.

## The Possible Derivation and Affinities of this Type of Genitalia.

*Galeopithecus* being such an anomalous animal in most respects, has been subjected to analysis by many zoologists in the hope that by some resolution of its systems and organs its true affinities could be determined. Leche has conducted such an analysis for the reproductive system, and his results may be summed up by saying that he finds genital affinities with lemurs (*Chiromys* and *Tarsius*), with Tupaia, with the Insectivora, and with Chiroptera. Chapman (8, p. 251) concludes that the external genitalia show most resemblance to those of the lemurs.

Without criticising this analysis, I will take the outstanding features of the genitalia of *Galeopithecus* and attempt to determine their nearest likenesses among possible allies.

The uterine condition of *Galeopithecus* finds its exact parallel in certain members of the Chiroptera. The work of Robin (see 10) furnishes several examples of double uteri in bats which show conditions in all respects identical with that described in *Galeopithecus*. It is to this source of information that Leche has turned, and I agree with him in selecting *Cynonycteris amplexicaudata* as the most exact parallel. The condition of the cervix uteri in this animal is especially striking in its similarity to that of *Galeopithecus*; Robin has figured the genitalia of this animal with one uterus pregnant, and I have thought it worth while to reproduce a drawing of his figure along with the figures of *Galeopithecus* (see fig. 1). The shortness or comparative absence of the urogenital canal is also a feature present in most bats as well as in animals higher in the scale.

As for the external genitalia, it is easy to determine that, with all their peculiarities, they have followed in their development that type which in previous papers I have designated *cloaca explicata*. In this, although they fall into line with Tupaia and with the lemurs, they are also like Chiroptera, and it is certainly to the bats that their resemblance is most marked. In the apparent transverse opening of the vulva they have their parallel in the Megachiroptera; the curious flattened clitoris is also found

among the bats, and a terminal perforation of the clitoris I have previously demonstrated in the young of *Myotis nigricans*. The male

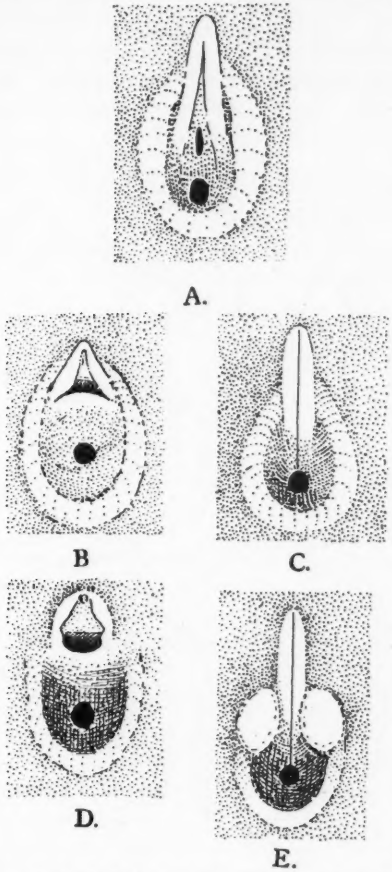



FIG. 5.—Probable derivation of type of external genitalia.

A, early phase of mammalian common type. B, fœtal stage of female bat. C, fœtal stage of male bat. D, female *Galeopithecus*. E, male *Galeopithecus*.

shows affinities with the Chiroptera in the form of the glans penis, which is found again in a somewhat modified way in many members of the order (see Robin, *op. cit.*, plates 5 and 6, etc.).

It is, however, when we take the whole form of the external genitalia,

and especially that curious skin fold which surrounds the anal orifice, that the resemblance to the Chiroptera becomes most striking; indeed, so far as I know, the only real approach to this condition is seen in the bats, and that only in the fœtal stages. The posterior portions of the cloacal margins are extremely prominent folds in the embryos of many bats, though in only a few—such as *Taphozus*—do they persist into the adult as anything comparable to the anal pouch of *Galeopithecus*. I have embryos of one bat (species not determined yet) in which the likeness to *Galeopithecus* is perfect in all respects, an anal pouch being present in both sexes, but especially in the male, which is proportionately as well developed as is the adult pouch of *Galeopithecus*.

I have figured a probable course for the development of the genitalia of *Galeopithecus*, and for the intermediate stage I have taken a common phase seen in bat embryos; the final stage as I have represented it might serve either for the adult of *Galeopithecus* or for the embryo of certain bats, the only point of difference being that I have represented the testes as descended (see fig. 5).

## The Mammary Glands.

There appears to be some uncertainty about the actual state of mammary development, for there are considerable discrepancies in the published accounts given by different authors. It is possible that the animal shows some individual variation in this respect, for the adult female that I have examined does not conform exactly to any of the published descriptions. In most works upon zoology the account as given by Dr Gray is quoted. According to Gray (see 2), "the teats are placed in pairs on a large gland." This is practically identical with the description as given by Leche; but Cantor takes a different view of the structure, for he says (6) "there are four mammæ situated in pairs one above the other, close to the axilla."

In the adult female that I have examined the mammary glands were evidently in a state of functional activity. The mammæ are large and somewhat pendulous; they are situated in the pectoral region towards the anterior margin of the axilla, the mass of the gland and the nipple being retained in the axillary space between the chest wall and the redundant skin fold that constitutes the parachute membrane. The skin over the gland is fine, it is not covered by the general body hair, and the whole breast is apparently of a pinkish flesh colour. The whole structure is best likened to a particularly pendant and flaccid human breast (see fig. 6). Cephalad and caudad, the prominence of the breast thins out as skin folds merging with the general body skin above and below the breast; upon the anterior fold of the right breast there is a minute skin papilla which I

presume to be a rudimentary and functionless nipple—this rudiment is wanting on the left side, where only one nipple is present. The functional nipples are large, the one upon the right side being considerably elongated; this is almost certainly the result of recent suckling, and it is obvious that the young exerts a considerable traction upon the nipple. I should think that it is extremely probable that the nipple is used as an "anchoring nipple" by the premature young in the same way as the marsupial teat is

FIG. 6.—Left mammary gland of adult female; this gland having only one nipple.

used. The likeness to the marsupial teat is striking; and in this connexion it is interesting to recall the functionally similar anchoring nipples of some of the Rhinolophid bats.

In the specimen that I have examined there are therefore two mammary glands each provided with one functional nipple, and upon one side only a functionless rudiment of another nipple placed immediately in front of the fully developed one.

### POSSIBLE TRACES OF A BROOD AREA IN GALEOPITHECUS.

Concerning the appearance of a pouch rudiment and ridges which I have figured upon the abdominal wall of the young female specimen there is a

great deal of uncertainty. In my young specimen it was conspicuous, and the figure depicts its outstanding features; in the adult I find no trace of it (fig. 2). The resemblance to a marsupium rudiment was at once obvious, and I had figured it before I had studied the work of Professor Parker. In his Hunterian Lectures of 1884 on Mammalian Descent, Parker first drew attention to the condition. His reference to it is not very precise, and practically no details can be gathered from the figure which he gave of it, but it is quite certain that he regarded it as a marsupial feature. Gervais has figured a young female in about the same stage of growth as the example demonstrated by Parker, and, although the figure is an excellent one, no trace of this formation appears. Leche was unable to discern it on an embryo supplied him by Dr Jentink, and almost all zoological works ignore its possible existence. Leche and others have gone further than this, for it is declared that even were such a structure as is described and figured by Parker to be present it could certainly claim no kinship with any basis of the marsupium. Leche dismisses it altogether from discussion as such a rudiment, for the reason that the nipples are not situated within it.

I am not certain that these sweeping assertions carry the weight that at first sight would seem to belong to them. The presence of this shallow pouch appears to be variable in the young, it certainly does not contain the nipples, and apparently it disappears in the adult, yet I think that none of these facts necessitates our putting it aside without further consideration. Very similar features in other Eutherian Mammals have before now been brought forward with claims to be considered as next-of-kin to the marsupium, and in the dismissal of their suit I think that the impression that they claimed to be rudiments of a highly specialised Diprotodont marsupium has influenced the judgment. To picture a structure as being a persistent remnant of an elaborated embryo-carrying marsupium of a Diprotodont is a thing very different from imagining it to represent that anatomical basis which, already present in the Prototheria, may or may not become more highly specialised in the Polyprotodonts, finally culminating in the extraordinary "marsupial pouch" of the Diprotodonts. As representing such an anatomical basis I am inclined to regard the shallow pouch to which Parker called attention, and the condition of which in my specimen I have illustrated. Among my reasons for so regarding it are that I do not think the anatomical basis which culminates in the development of a pouch in some few animals is always rightly understood; that very much more striking imitations of the pouch, and other "marsupial" features, are present in some, even adult, Insectivora; and that attention has already been called by many zoologists to dental resemblances between *Galeopithecus* and *Perameles*.

## The Pelvic Symphysis.

Without exception, I believe, zoological works which mention the condition of the symphysis describe it as being "long." Flower (11) says it "is long, as in the Carnivora, and becomes ankylosed." When the mere statement is made that the symphysis is long, it is difficult to know what type of symphysis is taken as a standard with which the comparison is made; but when the pelvis of Carnivora is instanced (although the instance covers a great variety of types) it is only possible to say that in comparison the symphysis of *Galeopithecus* is *short*. Of the whole

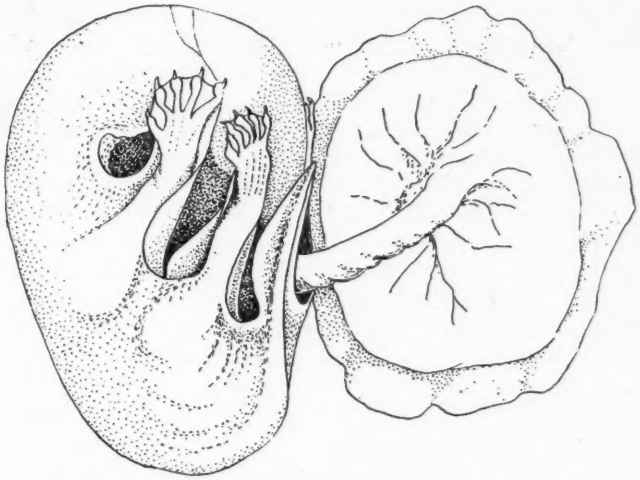


Fig. 7.—Embryo and placenta; from Harrison Allen, after Gervais.

ischio-pubic ramus, from the spine of the pubis to the tuber ischii, the symphysial area is less than one-fourth in *Galeopithecus*, and is therefore somewhat shorter than the corresponding area in man, and less than a half of the same area in the dog. It is certainly longer than the symphysis found in most bats, for in them the symphysial area tends to diminish until, in most families, it is lacking altogether; but compared with the primitive type of mammalian pelvic girdle, that of *Galeopithecus* is distinguished by the shortness of its symphysial area. This point is not without its importance, and will be dealt with fully elsewhere.

## Development and Placentation.

I do not know of any published work upon the details of embryological development of *Galeopithecus*. Gervais has figured an embryo which was received from Diard, who collected it in Java in 1845. This figure is reproduced by Harrison Allen (12), and from his reproduction I have drawn fig. 7. The placentation as it is shown in this figure agrees with that of the Chiroptera and Insectivora, and differs, of course, from that typical of the lemurs.

## Summary and Conclusions.

Even without an examination of the actual fœtal stages it is quite possible to determine with, I believe, certainty the route which the external genitalia of *Galeopithecus* have followed in their development. It seems obvious that they have undergone that cloacal outfolding which is seen in all the Primates and in the Chiroptera, as well as in some of the Insectivora. With all these groups, as Leche and others have shown, *Galeopithecus* shows affinities in other systems and organs. But the study of the genitalia affords this amount of precision, that though individual features may be seen paralleled in representatives of the Primates or of the Insectivora, the whole picture is seen only in the members of one order—the Chiroptera. The whole adult picture of the genitalia of *Galeopithecus* is seen with remarkable faithfulness in the embryos of bats; and even in some adult bats the likeness is very striking. *Taphozus perforatus*, for instance, agrees with *Galeopithecus* in uterine form as well as in the characters of the external genitalia and the presence of a circumanal pouch, which is here very much better developed in the male. In the whole of the genitalia *Galeopithecus* shows no feature which is not seen again in members of the Chiroptera, and in the embryos of this order an identical combination of all the peculiar features is common.

Judging from this one system alone, one might therefore conclude that the affinities of *Galeopithecus* were most strongly with the bats, and that the adult of *Galeopithecus* resembled most closely the embryonic stages of that order. I do not think that this finding is at all out of harmony with the evidence derived from all the other systems and organs; and although other systems are outside the scope of this paper, I would point out the similarity of the adult condition of the patagium of *Galeopithecus* to the embryonic condition of that of the bats. Such a conclusion is of course by no means new. According to Parker (*op. cit.*), "it might be said of Nature that she tried her 'prentice hand on the Colugo, and then

afterwards she made the bats"; and he summed up the position by saying "We have in this beast a scarcely modified Early Tertiary bat."

Chapman, although he follows Leche in likening the genitalia to those of the lemurs, concludes that "there can be but little doubt that the Chiroptera are the descendants of *Galeopithecus*, or more probably that both are the descendants of a *Galeopithecus*-like ancestor."

If it be accepted that, even on broad lines, embryonic conditions are akin to ancestral stages, then, from a study of the genitalia of *Galeopithecus*, these quoted opinions can be well supported, for it is only possible to conclude that *Galeopithecus* represents an ancestral form from which the Chiroptera have sprung.

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## REFERENCES.

(1) Waterhouse, G. R., "On the Genus *Galeopithecus*," *Trans. Zool. Soc.*, 1838, Bd. ii., 1841, p. 335. This paper deals with the specific characters of skulls.

(2) Gray, J. E., *Catalogue of Monkeys, Lemurs, and Fruit-eating Bats in the Collection of the British Museum*, 1870, p. 97. Deals with specific characters and nomenclature.

(3) Dennys, N. B., *A Dictionary of British Malaya*, 1894, p. 136.

(4) Hose, C., *A Descriptive Account of the Mammals of Borneo*, 1893, p. 37.

(5) Wallace, A. R., *The Malay Archipelago*, p. 104.

(6) Cantor, Theodore, M.D., "Catalogue of Mammalia inhabiting the Malayan Peninsula and Islands," *Jour. Asiatic Soc.*, Bengal, vol. xv., 1846, p. 178.

(7) Leche, Wilhelm, "Über Säugethiergattung *Galeopithecus*. Ein Morphologische Untersuchung," *Kongl. Svenska Vetenskaps-Akademiens Hardlingar*, Bd. xxi., No. 11, Stockholm, 1886.

(8) Chapman, Henry C., *Proc. Acad. Nat. Sci. Philadelphia*, April 1902, pp. 241–254, and plate xi. A good *résumé* in English of all points of affinity of *Galeopithecus*; largely founded on the work of Leche.

(9) Gervais, "Mémoire sur les formes cérébrales propres à différents groups de Mammifères," *Jour. de Zool.*, t. i., 1872, p. 425.

(10) Robin, H. A., "Recherches anatomiques sur les Mammifères de l'ordre des Chiroptères," *Ann. Sc. Nat. Zool.*, 1881; see especially pp. 111–175.

(11) Flower, W. H., *An Introduction to the Osteology of the Mammalia*, 3rd ed., 1885, p. 320.

(12) Allen, Harrison, "On the Embryos of Bats," *Contributions from the Zoological Laboratory of the University of Pennsylvania*, vol. i. No. 2, 1895, pp. 29, 30.

# OBSERVATIONS ON THE POPLITEAL GROOVE ON THE FEMUR.

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THE popliteal groove which is so prominent a feature in almost all femora has always seemed to be more explained away than actually accounted for. It is constant in occurrence, direction, and position, and the causative factors must therefore be correspondingly constant.

The fact that the tendon of m. popliteus is inserted into it far forward —though not at its most anterior part,—and also that the tendon lies in the posterior part of the groove in acute genuflexion, has led to the present description that the groove is caused by the presence and pressure of the tendon in that position of genuflexion.

FIG. 1.—To represent the anterior part of the popliteal groove.

X, point of insertion of tendon of m. popliteus; A, part of the groove anterior to that point; B, part of the groove posterior to that point.

The main objections to such a view are first of all that the groove extends anteriorly quite half an inch beyond the insertion of the popliteus tendon (fig. 1). The groove thus carried forwards is directly continuous with the posterior part, and, so far as I know, this anterior prolongation has not previously been differentiated. It is clear that the tendon can have no share in producing at least this anterior part, to which, indeed, it bears no relation. Again, if the tendon causes the groove, the groove would be at least as wide posteriorly as at the point of tendon insertion; indeed, the tendency would be for it to be wider posteriorly, as the tendon begins to expand when traced medialwards to become the muscle. But on examination we find that the groove becomes rapidly narrower when traced posteriorly, and finally ceases at the upper part of the posterior rim of the condyle (fig. 2). Now, the pull of a tendon is usually in a straight line, and we would expect, if an osseous groove is formed, that it would produce a straight gutter for itself. But the popliteal groove is a curve which in the erect position extends from below and in front of the most prominent part

of the external condyle upwards and backwards parallel to the articular edge. It is difficult to see how a tendon acting in a straight line can produce a curved imprint on bone.

Lastly, if a tendon is going to produce an osseous groove for itself it will do so, other things being equal, in a position where it is constantly lying and in a direction in which it is constantly acting, as does the biceps tendon on the humerus. But the tendon of m. popliteus lies in the groove of that name only in acute genuflexion—an attitude only momentarily assumed; whereas in the usual position—the erect position—only a faint bevelling is produced by the tendon, and that on the anterior part of the inferior lip of the groove (M'Kay).

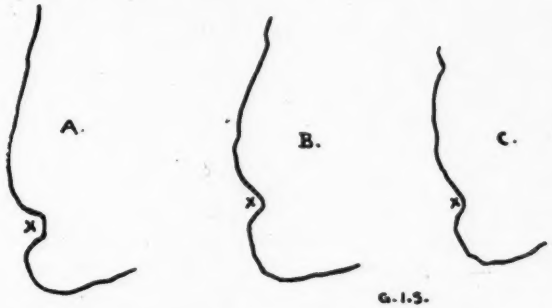


FIG. 2.—To represent the width of the popliteal groove in various situations.
A, at the insertion of m. popliteus; B, posterior to A; C, still more posterior to A.
Three tracings from a sectioned specimen.

These considerations, though important in showing what does *not* cause the groove, bring us really no nearer to what does cause it. In considering this problem certain important morphological considerations arise.

The popliteus muscle in man and in most other mammals is attached to tibia and femur; but in marsupials, as in reptiles, it stretches between the tibia and the head of the fibula, and is a rotator fibulæ. In the lemur an intermediate stage is seen (Gordon Taylor and Bonney), the tendon being inserted on the external femoral condyle, while a sesamoid bone representing its fibular attachment (the true head of the fibula?) is developed in the tendon.

Now, the external (fibular) lateral ligament derived morphologically from the m. peroneus longus (Sutton) exerts a strong bracing pull on its attachments, especially in extension—the most common attitude. This pull will act all the more powerfully on the femur as that bone inclines downwards and medially and forms a distinct angle with the vertical fibula.

When a tendinous or ligamentous insertion exerts traction on its osseous attachment it is a rule (Wolff's law) that a bony elevation arises at that point as though the bone were being drawn out locally. Now, putting these considerations regarding m. popliteus and the external lateral ligament together, our hypothesis is that the sesamoid bone described in the lemur has in man and the higher mammals travelled up and as it were fused itself on to the femur; it is then pulled out into a sharp edge by the localised action of the external lateral ligament, as described. This explains the development of the anterior part of the upper lip of the groove and also of the anterior part of the external epicondyle of the femur.

The posterior part of the external epicondyle of the femur bears the imprint of origin of the lateral head m. gastrocnemius. This muscle pulls in an inward and downward direction, and, its origin being more diffuse than the insertion of the external lateral ligament, its traction elevation will be of greater extent, but not so well defined as the other.

It will be noted that the upper lip of the popliteal groove formed by these traction forces is almost horizontal and is absolutely so on slight flexion of the hip.

With regard to the lower lip of the groove, all that is to be seen is the everted flange of the condylar articular margin, smoothed out at one part where the tendon of m. popliteus passes over it. An anterior groove for the external lateral ligament so often described is not present in any specimen; indeed, in every movement of the joint the ligament and tendon cross the lower lip of the groove at one and the same spot, the ligament of course being superficial to the other. Supporting this theory of causation of the lower lip of the groove I have found in the full-time fœtus the lower lip blunt and rounded, not yet having been subjected to weight pressure; also, the part of the groove previously described as lying anterior to the insertion of the popliteus tendon has not yet developed for lack of the ligamentous pull, owing to the fœtal position. In a subject ætat. six years this anterior part was becoming quite well defined, as was the entire inferior lip, the adult conditions now coming into play.

The floor of the groove is thus, according to these views, normal femoral surface, the lower edge a pressure ridge, and the upper lip a traction ridge. This explains why the inferior lip of the groove is parallel to the articular margin.

This hypothesis I believe will stand investigation, as it explains the conditions present, which the usual description quite fails to do.